1964

# A review of the concept of military worth and its application in military decision making.

Brewin, Robert L.

Monterey, California: U.S. Naval Postgraduate School

# A REVIEW OF THE CONCEPT OF MILITARY WORTH AND ITS APPLICATION IN MILITARY DECISION MAKING

ROBERT L. BREWIN

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Robert Leroy Brewin

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# A REVIEW OF THE CONCEPT OF
# MILITARY WORTH
# AND ITS APPLICATION IN
# MILITARY DECISION MAKING

by

Robert L. Brewin
Lieutenant Commander, Supply Corps, United States Navy

Submitted in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE

IN

MANAGEMENT

United States Naval Postgraduate School
Monterey, California

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Robert L. Brewin

This work is accepted as fulfilling
the research paper requirements for the degree of

MASTER OF SCIENCE

IN

MANAGEMENT

from the

United States Naval Postgraduate School

ABSTRACT

Military decision problems are growing increasingly more complex, requiring rigorous structured methods to be applied for superior solutions and decisions. In many cases the military decision-maker is faced with a set of alternatives from which he must choose. Rational and consistant judgement can only be made by attempting to maximize the military value or utility of his decision. The decision-making process is described, along with a structured approach to military decision-making by economic analysis and the application of mathematical techniques. Some basic elements of measurement theory and utility theory are dealt with because of their importance to military worth scales and military worth measurement. The military worth concept is developed and commented on. The use of psychometric techniques of introspection and behaviorism and the use of game theory are examined as possible methods in developing measures of military worth. The application of military worth techniques to some general decision-making problems and to some specific logistical decision-making problems is discussed. Finally, a most important step forward in the measurement of military value through readiness indicies is reviewed.

ACKNOWLEDGEMENTS

The information presented in this review has been gathered from many sources and not without assistance. I wish to express my indebtedness to CDR Sherman W. Blandin, Jr., SC, USN for his guidance in formulating the problem and for his excellent advice, without which I would have been unable to have developed this manuscript. I should like to express my appreciation for the patience and understanding of my wife in her typing of the rough manuscript. Finally, I want to thank Erroll McMahan for an excellent typing job of the smooth manuscript.

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INTRODUCTION

## I. PURPOSE

The military decision-maker, whose attitudes or behavior satisfy certain consistency requirements, is faced with the problems of choosing from a set of alternatives, each associated with a particular cost and effectiveness. Rational and consistent judgement can best be made by maximizing the military value or utility of this decision. If probabilities are introduced into the decision, then the problem becomes one of maximizing expected military value. The determination of that feasible alternative which provides the maximum military worth, value or utility (preferred or most satisfying) requires the use of military worth scales.

It is the purpose of this paper to briefly examing the decision-making process and some associated problems, to show the importance of using structured decision-making techniques, to discuss some basic concepts in measurement theory and utility theory, to explore the procedures and methods for deriving military worth measures, to discuss the application of the military worth measures in decision problems, and finally to briefly survey some general and specific military decision problems which may profitably use military worth measurements.

## II. IMPORTANCE OF CORRECT MILITARY DECISIONS

The importance of making correct military decisions can not be overemphasized. Livingston has stated that in order to catch up with the Soviets today, to be ahead of them tomorrow, we need better decision

making in weapons development.[1] Incorrect or poorly made decisions can lead to imbalances between opposing forces. Too great an imbalance could be disastrous.

## III. NATURE OF THE MILITARY DECISION PROBLEM

Added to the growing and changing nature of the threat from the Communist nations are a myriad of problems requiring analysis and decisions by the military decision-maker. These decisions are made even more difficult by the growing economic, political, social and technological complexities of the world today, which introduce an almost unlimited number of variables into an already complicated problem. The consideration of all these variables and the weighing of their significance on the problem at hand in arriving at a decision is beyond the ability of the human mind. These problems must be reduced to a manageable proportions and feasible courses of action found. Only by attacking and solving a variety of individual problems can we hope to discern the general patterns to the solutions that we hope exist.[2]

## IV. CLASSES OF MILITARY DECISIONS

Military decisions may be classified by kind as well as by level. Hitch and McKean have found it useful to distinguish the following as three basic classes of military decisions: operations decisions, procurement or force composition decisions, and research and development decisions.[3] Operations decisions may be further classified as strategic,

[1] J.S. Livingston, "Decision Making in Weapons Systems, "Harvard Business Review, Vol. 36 (1958), p. 127.

[2] O. Morgenstern, TheQuestion of National Defense (New York: Random House, 1959), p. 163.

[3] C.J. Hitch and R.N. McKean, The Economics of Defense in the Nuclear Age (Cambridge: Harvard University Press, 1963), p. 131.

tactical, and/or logistical decisions. Strategic decisions are decisions concerning long range, broad, overall planning and execution, and basic disposition of the resources made available to the military. Tactical decisions are decisions concerning best courses of action and the manner of utilizing resources which have been committed to a particular activity when in direct enemy contact or in immediate operational support. While each of the above classes of decisions involves different considerations in their use, the basic structure of the decision problem is common to all.

In addition to the action type decisions described above, other types of decisions include decisions of understanding, of recognition, and of enterprise. These decisions are concerned with constructive, purposive, or creative aspects of human behavior. All are interrelated. The quality of decisions effects the quality of the organization, the degree of human satisfaction, and the effectiveness of the organization. In this review we shall concern overselves only with the decisions of action.

## V. BASIC STRUCTURE OF THE DECISION PROBLEM

The basic structure of the decision problem can be divided into nine fundamental concepts or parts: sizing-up situations, formulating policies, discovering opportunities, assessing risks, planning programs of action, organizing administrative personnel, putting plans into action, controlling parts of and all of vital situations, or keeping informed, and finally following up and reappraising previous thinking and actions in the light of unfolding events.[4] Essentially it may be

[4] G.A. Smith and C.R. Christensen, Policy Formulation and Administration (Homewood: Richard D. Irwin, 1962), p. XVIII.

thought of as the process of translating thoughts into action.

## VI. DECISIONS OF ACTION

### Major Decision-Making Groups

The three major decision-making groups, Business, Political and Military, are all faced with action type decisions. The business entrepreneur is blessed with the market and pricing system, which incorporates a vast amount of information, free, that he needs to know in order to operate with in the complex world of today. With the help of this system, a business entrepreneur in a free enterprise system can compare expected costs with expected sales and profits when he has to decide which allocation of his scarce resources is better than another. All are expressed in dollars, or in other words by numbers. The military decision maker is not so fortunate as to have such a market system at his disposal.

### Subjective Military Evaluations

Many of the action decisions in the military are determined mainly by subjective military evaluations. In a great many cases these evaluations are made on intuitive judgements based on the intelligence, experience, imagination, foresight, vision and feelings of the individual decision maker. Generally, this consists of judgements that are neither definable nor rigorous, made by military personnel, often using procedures that are variable. Brock states that,

> this does not imply that evaluation methods are without value. However, such procedures require systematization and substantiation through investigations of measurable quantities that can either support, extend or contradict these evaluations.[5]

[5] P. Brock, et al. "Techniques for Evaluating Military Organizations and their Equipment," _Naval Research Logistics Quarterly_, Vol. 9 (1962), p. 212.

While these intuitive judgements have in many cases proved highly successful, it is necessary to supplement intuition and judgement because of growth problems, difficult to resolve critical factors, interrelationships, the numerous courses of actions possible, and the difficulty of evaluating outcomes in an unsystematic manner.

Dynamic Aspect

The problem is further complicated by the element of time. Since the enemy is making his plans, provisions must be made in one's own plans for flexibility that will permit timely change to meet not only the enemies changing plans, but the changing enviroment as well; and all this without compromising the organization's objectives. The military is faced with the problem of developing adequate decision making techniques to bridge the gap between the present and the very uncertain future.

## VII. UNCERTAINTY

The most difficult part of decision making is dealing with the future. If we were able to foresee the future with certainty then a great deal of the difficulty would be removed from decision-making. Morgenstern states that the military is concerned with the problem of decision-making under uncertainty, where the uncertainty is not of the simple, well-understood kind to be dealt with by probability theory, but is of the highly complex nature arising from the strategic moves of the opponent, who labors under the same difficulty.[6]

The decision-maker must understand the nature of the uncertainties facing him and how to deal with them in order to improve his decisions.

[6]Morgenstern, op. cit., p. 264.

Uncertainties are introduced by human behavior, changes in environment, and actions and reactions of the enemy. Enthoven describes these uncertainties as operational factors, time and cost to develop weapons systems, enemy behavior, his weapon systems and forces, the behavior of other countries, and conceptual uncertainties.[7] To this growing list of uncertainties could be added technological uncertainty, uncertainty of planning factors, uncertainty about strategic context, and finally statistical uncertainty (chance element in recurring events).

Efforts in dealing with uncertainty have been made by determing past frequency patterns and then projecting them into the future, as a probability of re-occurrence. In most cases facing the military decision-maker, the uncertainties are not merely statistical, where the fluctuations are the process of a known probability distribution, but are largely stochastic, or not well understood. Other decision-makers form in their mind a subjective probability or degree of belief regarding an expectation. That is to say they make an intuitive judgment.

## VIII. NEED FOR A STRUCTURED APPROACH TO MILITARY DECISION PROBLEMS

Clearly, it can be seen from the foregoing that if order and meaning is going to be given to the complex military decision problem, a systematized approach, tailored to the needs of the military, must be developed. Morgenstern stresses the need for such an approach in the

[7] A.C. Enthoven, "Economic Analysis in the Department of Defense" (Address before the American Economic Association at Pittsburgh, Pennsylvania, 29 December 1962), p. 14. (Mimeographed).

following statement:

> We do need guidance. It can come only from combining experience with a highly developed, proven system of thought. Loose thinking is seldom permissible. It should be avoided like the plague in the discussion of our strategic military problems since the answers we need affect our survival, individually and as a nation.[8]

The method or methods selected should clearly and simply set forth the values, effectiveness and costs involved in a proposed set of alternative courses of future actions.

## IX. A STRUCTURED APPROACH TO MILITARY DECISIONS: AN ECONOMIC APPROACH.

### Essentially Economic Problems

A structured approach to problem solving and decision-making, which has found considerable application in the military in recent years, has been developed by Hitch and McKean.[9] They have stated that National Defense Problems, while eventually requiring a human value judgement, are essentially economic problems of allocation of scarce resources among various alternatives to accomplish a stated objective or mission.[10] Mission implies the selection by an authority of an objective, usually well defined and which must be reached within a certain time period, through a chain of operations to be chosen and performed by the agents in charge of the mission and responsible for its successful conclusion, in spite of eventual difficulties and obstacles which can not be well defined at the beginning of the operations. Because National

[8] Morgenstern, op. cit., p. 5.

[9] Hitch, op. cit., p. 5.

[10] Ibid, p. 1.

Defense Problems are essentially economic problems they can be structured by the use of the economic analysis techniques. Economic analysis, whether quantitative or qualitative, will usually attempt to determine the utility of alternative systems by examing the effect on military capabilities, whenever these occur.[11]

Need For Economy

A second reason why Hitch and McKean recommended the economic analysis approach was because within government there is neither a price mechanism which point the way to greater efficiency, nor competitive forces which induce government units to carry out each function at minimum cost.[12] Economy and efficiency are two ways of looking at the same characteristics of an operation. Given a fixed budget or other fixed resources, management maximizes attainment of an objective or maximum production by using or combining the resources in an efficient or optimal manner. On the other hand, if the objective is fixed, management must economize on the use of resources so that costs are minimized.

It must be realized that economizing does not mean scrimping, for the more expensive item initially may well be in the long run, with all other factors considered, the most economical. Economizing does mean

[11]Ibid, p.132.

[12]Ibid., p. 107. Hitch and McKean also stated that efficiency would be improved by improved institutional arragnement and increased recognition and awareness that military decisions are in one of their important aspects economic decisions. They go on to state that unless the right questions are asked, the appropriate alternatives selected for comparison, and an economic criterion used for choosing the most efficient, military power and national security will suffer. It must however be remembered that economics is only one aspect of the military decision, there are also the military, political, social and moral aspects to be considered.

the combining or mixing of fixed scarce resources at least cost to achieve effectively a stated objective. Hitch and McKean have stated that the essential thing is the comparison of all the relevant alternatives from the point of view of the objectives each can accomplish and the costs which each involves; and the selection of the best (or a "good") alternative through the use of appropriate criteria.[13]

Elements of the Economic Analysis Approach

The essential elements of a military problem of economic choice, whether its solution requires advanced mathematics, high speed computing equipment, or just straight hard thinking, are the following: an objective or objectives, alternatives, costs of resources, a model or models, a criterion or criteria, and a value judgment.[14] Added to these elements should be recognition of the true nature of problem or problems facing the military decision maker.

Recognition of the Problem

Consciousness of a problem-provoking situation and recognition of the problem is the first step in the decision-making process. Once the military decision-maker recognizes the existance of a problem he must take the following steps: gather information, assess the significance of what he learns, sort the important from the unimportant, trace symptoms back to basic causes, and select out the main thing or things toward which he is to devote more intensive attention.[15]

[13]Ibid, p. 118. This statement should be amended to say "the appropriate economic and military criteria." Certainly any adequate military decision requires the evaluation of the military worth of the alternatives.

[14]Ibid., p. 118-120.

[15]Smith, op. cit., p. XVIII.

By this procedure he should be able to clearly define the right problem and the critical factors causing the problem.

Several difficulties arise in defining the problem. These are selecting the context of the problem and making the necessary assumptions. With many variables impinging on the problem, it is necessary to determine those that art critical and make certain assumptions about the balance of the factors. Also, if a quantitative solution is sought, further complications may be introduced because some of the critical factors are unmeasurable, requiring additional assumptions to be made. A word of caution here is that the military decision-maker must shun reasoning based on untested and unquestioned assumptions that become self-deceptive.

The military decision problem must be considered in its proper scope. Treating broad high level problems by economic analysis may not be adequate, since we are no longer analyzing a problem with a given and definite context and with specific equipment. There may not be clearly defined objectives. Instead, we are trying to design, not analyze, a system that will operate satisfactorily, in some sense, under a variety of contigencies that may arise in a future that is seen only dimly. At the lower levels we have the problem of choosing the context and the elements that will be permitted to vary in the systems compared. Hitch and McKean make this statement concerning the contextual problem:

> The broader the context the less the danger from inconsistent criteria and the less likely it is that significant spillover effects will be missed. But breadth of context and any increase in the number of variables have to be purchased by drastically increasing the complexity of the analysis, which all this implies in terms of research manpower, expense and time.[16]

[16] Hitch, op. cit., p. 129.

Spillovers may be defined as the effects (favorable or unfavorable) on other entities outside the context of the problem by some of the consequences of the solution to the problem.

Objectives

McDonald has described a decision as a choice of alternative means by which to move toward an objective.[17] The objective may be a single goal or a combination of several objectives, which may be in conflict. It is the specification of purpose and goals of men working cooperatively within the frame work of some type of organization and the actions taken to achieve these goals which is so important to the foundation of the problem. These goals or objectives must be clearly defined and they must be understandable and explainable. This includes setting both long-range and short-range objectives.

Objectives are not static. The military leader changes character of the organization by changes or constant adjustment of his philosophy and objectives to a changing environment. It certainly may be said that the ultimate objective of the military is victory in war.

Alternatives

Alternatives can be looked at from two aspects. There are alternative ways of mixing inputs which yeild alternative outputs. Technology defines the possible input alternatives. Technology can be thought of as the physical things which are involved in converting an input into an output of an activity. The rate of technological growth and the current state of the art are essential factors in National Defense and therefore to the military decision-maker. This is true because technology defines

[17]McDonald, Fortune (August 1955), p. 3.

the possible input alternatives and therefore the output alternatives which can be placed in the hands of the military for the defense of the country and countering enemy actions.

Faced with the choice between alternative outputs, the military decision-maker must predict what his opponent or opponents will do and what effective actions he can take based on an evaluation of information concerning possible actions of the enemy. The decision-maker will have to evaluate the risk of his alternatives in the light of the intelligence he has on enemy actions. Time, temperament and circumstances may effect the rationality of the decision.

The economic problem is to choose that input alternative which is most efficient (maximizes the attainment of the objective with the given resources) or economical (minimizes the cost of achieving the given objective).[18] The most efficient input alternative is also the most economical.

The problem facing the decision-maker is: given a set of resource constraints, how shall they be mixed to give what alternative outputs? The amount of the resources is controlled by their cost and availability and by the funds allocated for the purpose to which they shall be used. The state of the art tells what alternative outputs can be made available. The better the state of the art the greater flexibility and options available. The outputs may be infeasible, feasible, economic, or optimal solutions. The optimal or near optimal is the desired solution, keeping in mind that if the decision-making process becomes too involved and time consuming because the one optimal is sought, then the

[18]Hitch, op. cit., p. 3.

decision-maker may have to settle for less. The solution selected, however, should have cost, benefits, and risks balanced and bring about greater assurance of both short and long range health of the organization. It certainly should pass the test: is it "better" than the other alternatives.

A principle problem in the selection of an optimal solution is sub-optimizing.[19] Sub-optimizing is the problem of optimizing at lower levels which when put together may not be the optimal solution of the whole.[20] In dealing with lower level problems the overall problem and objectives must be kept in mind, as partial optimization may be inadequate. Sub-optimizing at lowest levels assumes decisions given at higher and collateral levels. Hitch and McKean caution that while analysis appears to become more manageable as we move to lower levels, limiting the context, and restricting the scope within which systems vary, has the tendency to cause the inter-related problems to become more formidable the further we move in this direction.[21]

## A Model or Models

Models are abstract representation of reality which help us to

[19] McCoskey described in [5] , p. 170, the impossible task of full optimization as requiring: (1) simultaneous consideration of all possible allocations of one's resources, that is, all possible alternatives and all possible allocations among those alternatives, (2) consideration of the probable impacts of all exogenous events (i.e., those not under the optimizer's control) and (3) the maximization, subject to certain initial constraints, of the utility function of the optimizer.

[20] Brooks gives an interesting discussion of sub-optimization on long-range planning decisions in [30] .

[21] Hitch, *op*. *cit*., p. 129.

perceive significant relations in the real world, to manipulate them, and thereby predict others. In no case are useful models photographic, reproductions of reality; if they were they would be so complicated that they would be of no use to us. The solution to the model will not be strictly applicable in all its quantitative features; but it will call attention to the chief qualitative features of the appropriate policy, the form it will take, and the directions in which it can be expected to vary with changes in the underlying parameters.[22] This qualitative information can be very useful in improving the intuition of the decision-maker, helping him to organize his data and his direct knowledge, and reducing the field of alternative policies to manageable proportions.

Models may take many forms, ranging from the physical model to the purely theoretical and mathematical.[23] Generally models express a set of assumed empirical relations among a set of variables. McCoskey has

[22] K.J. Arrow, Social Choice and Individual Values (New York: John Wiley and Sons, 1951), p. 18.

[23] Brooks states in [30], p. 163, the reason that economic models can not be predictive, in the sense that physical models are, is that the fundamental concepts entering into the definition of the state of an economic system do not obey Conservation Laws. However, if economic models can not be dynamic, their static relations, given some definition of value, are always specific and constrained. The model does bring in explicity the most important constraints affecting the feasibility of the objectives being studied.

this to say concerning models of military conflict:

> Models of some systems are, of course, extremely difficult to construct. Probably none is more difficult to construct than a model of conflict, especially armed conflicts. Here there is interaction within each system and between the two or more contending systems. Armed conflict not only produces its own peculiar tensions, but requires careful study of the things that are aggregated under the heading of attrition and the effects of tension and of attrition are the very things which can not be simulated, except approximately, and then only by the introduction of historical evidence and theoretical calculations into the analysis of the data derived from the simulation of the action.[24]

Criterion

A criterion is the test by which one alternative output or system is chosen rather than another. The criterion or criteria selected may take many forms. It may be a rule, or it may be a measure of some kind. The criterion may be factual or value or both. The aim is the selection of an optimal solution. In many cases application of a criterion may result in selection of an efficient system, relying on the intuitive judgment of a well-informed decision-maker to select one of the efficient systems in the neighborhood of the optimum.[25]

Selection of an appropriate criterion is a difficult task. The selection must be appropriate to the level at which the decision is being studied. It must be consistent with higher level criteria and ultimately with the welfare of the organization or group in which the decision-maker is really interested. In developing criteria he is trying to develop scales of effectiveness.

One method of expressing the criterion is through an objective

[24]J.F. McCoskey and F.N. Trefethen, Operations Research For Management (Baltimore: The John Hopkins Press, 1954), p. 263.

[25]Hitch, op. cit., p. 120.

function. Generally the objective function expresses the relationship of the alternative outputs from the model. The objective function is a function such that a higher value derived from it represents a more desirable state of affairs from the viewpoint of the organization. Ideally, the decision-maker would like to have computational methods which lead to an optimal solution-that is; to the determination of those values of the output alternatives which maximize the objection function subject to the constraints implied by the model.[26]

## X. SCIENTIFIC APPROACH TO MILITARY DECISION PROBLEMS

### Introduction

A second structured method in handling decision-making is the scientific approach. A brief outline of this approach is shown in Appendix A. The scientific approach finds wide application in the approach to decision problems in the operational area. The efficient and skilled use of scientific investigating techniques leads to new, more critical, more refined investigations. When problems are stated intuitively, and the methodology is largely heuristic, the most that can be expected of results are attenuated statistical reliabilities.[27]

### Modern Tools Used in Managerial Analysis and Decision Making

Both the scientific approach and the economic approach have had growing influence in military decision making procedures because of the growing complexity of the problems and because of the growth of modern tools and techniques of managerial analysis and decision making. Techniques have been developed to handle complex problems and to cope with variability

[26] Arrow, *op. cit.*, p. 16.

[27] Brock, *op. cit.*, p. 228.

and lack of information. A good many of the techniques have been developed through Operations Research Groups with the combined talents of mathematicians, physical scientists, economists, and social scientists. It is useful to the military decision-maker to know of the existance of these tools and their possible application. Some of these major techniques are listed in Appendix B.

## XI. PRECAUTION IN THE USE OF THE STRUCTURED METHODS IN DECISION MAKING

Care must be taken in the application of both the economic and the scientific approaches to managerial analysis and decision-making, particularly quantifying values.[28] Many important variables bearing on the problem are unmeasurable. This unmeasurable data, which can not or is not quantified, may be disregarded as irrelevant in the application of quantitative techniques, when it is essential to the problem and should be incorporated into the solution of the problem. Quantitative methods may give the appearance of substituting the objective for the subjective, but do they measure the right things? Weinwurm makes the following provision in the use of quantitative techniques:

[28]Another drawback is that in quantifying factors they become fixed or constant and disregard the temporal aspect, where time changes all factors. In any group problems in which a decision depends on information available and that, in turn, depends both on the decisions of other people and when they were made, timing quite obviously influences the over-all behavior of the group; i.e., the problem of static vs. dynamic considerations. An interesting discussion in this area can be found in [4], pp. 489-491.

> Provided that similar factors represent a large majority of all those which have to be considered in managerial decision making and that quantitative data far outweigh non-quantitative ones, there may be a favorable situation for the application of the probability concept and of the scientific method in a manner similar to that in the physical sciences In this way, the problem can be reduced to a question of fact and thus be decided in each particular instance on the basis of the available evidence. It may be accepted that there is a proper field for the application of the scientific method in managerial decision making just as in the physical sciences. Yet its scope and significance remains to be determined. There cannot be any valid presumption regarding the universal and uniform applicability of the scientific method in the field of management.[29]

A more thorough discussion of some of the limitations of the scientific approach to management decision problems is given in [60].

## XII. BENEFITS OF THE STRUCTURED METHODS IN DECISION-MAKING

In spite of these limitations, economic analysis and scientific methods provide useful methods in structuring the decision-making process for the military manager and provide additional insight into the problems of decision-making. Mills makes this statement of benefits of structured methods:

> As technical and organizational complexities in the military increases in the future, the military decision makers will comes to lean more on such techniques. While no decision mechanism can be devised that will completely escape the basic uncertainties and complexities that plague large problems of decision, yet a formal analytic system that will encompass many alternatives, and blend the contributions of many scientific disciplines, is steadily being improved.[30]

In so doing, it is hoped that more rational and consistant judgments will be promoted. However this is only an aid and not a substitute for

[29]E.H. Weinwurm, "Limitations of the Scientific Method in Management Science," Management Science Vol. 3 (1957), p. 229.

[30]H.F. Mills, "Looking for Something?", Newsletter (December 1960), p. 21.

common sense and sound judgment. In any event the military decision maker must continue to examine ways of improving his choice of pay-offs, his criteria for judging the relative merits of alternative future weapons systems that might be developed, and the balance of military forces that might be procured.[31]

## XIII. EVALUATION AND COMPARISON OF ALTERNATIVES

### Need For A Suitable Measure

Probably the most difficult aspects of the decision-making process is the development of a suitable measurement or criterion of evaluating the various alternatives that are available or developed for comparison. Measurement is the key to success. There is a need for relating the alternatives to the objectives that the decision maker wishes to maximize. Criteria are the practical counterparts of, or substitutes for, the functions which one would like to maximize in choosing among alternative courses of action. Criteria that can be used in actual problems are usually not the function whose maximization is desired; rather, they are approximate indicators of this function.

The calculation for quantitative solutions based on the wrong criteria is equivalent to providing answers to the wrong questions. Unless adequate methods of evaluating criteria and choosing good ones are developed, quantitative methods may prove more than useless. One of the main reasons that criteria selections are difficult is the fact that the decision-maker always deals with incomplete optimization and sub-optimization.

[31] D. Brooks, "Choice of Pay-Offs for Military Operations of the Future", Operations Research, Vol. 8. (1960), p. 160.

Economic Criterion

As a partial answer to the criterion problem, Hitch and McKean make the following statement:

> Military choice can be a very subtle and complex matter. At its heart one generally finds crucial issues of criterion selection, values and intangibles, and of risk and uncertainty about nature, technology, and enemy reactions. No simple formal model of choice is likely to be sufficient for a satisfactory analysis of most real military problems. But it is often enlightening to formulate parts of the problems of choice in economic terms, that is, in terms of discovering the most effective uses of limited resources.[32]

In economic consumer theory under a free enterprise market system the individual consumer achieves the most effective use of his limited resources if he maximizes his subjective economic utility or satisfaction. The value or utility of the alternatives available to him are expressed in the prices and quantities of various goods which he is willing to buy with his fixed income. The business entrepreneur values various alternatives by the amount of profits they will return to the firm. He wishes to maximize profits. Thus in the business world the common denominator is profit measured in dollars.

Military Worth.

The military has no such conveniently expressed common denominator. He can evaluate the cost and the quality of various alternatives, but he needs a common measure or value to relate the military value of various alternatives to the stated objectives. In years past little effort was made to quantify military worth, but developments in utility and probability theory, improvement of measurement techniques and development in mathematical formulations have given added emphasis to the

[32]Hitch, op. cit., p. 361.

possible quantification of subjective data. By questioning and weighting answers it is possible to develop non-quantitative attitudes into quantitative data and thus make it suitable for mathematical representation.

The quantification of military worth measures, along with the quantification of cost and quality, can promote rational and consistant judgments. Using these values in conjunction with improved electronic data processing equipment and programming techniques it is possible to compute the consequences of thousands of alternatives. The final result is the selection of better alternatives.

Succeeding chapters will discuss some basic measurement techniques and a brief review of utility theory. With this as a background we shall see how military worth scales can be developed and how military worth measured by these scales. Finally, we shall discuss some general and specific applications of military worth measures to improving military decision making.

CHAPTER II

MEASUREMENT SCALES

## SCALE VALUES

If we are going to measure military worth, values or utilities, a scale must be devised to represent these values so that various comparisons and mathematical manipulations can be made with these values. Scales may be considered by the properties necessary for their existence and by the procedures required to construct them. Measurement scales may be selected by comparing the analytical potential of a scale with the analytical demand to be made upon it.[2] Two general aspects of scales may be examined to determine their analytical potential. First is the operational character of scale values. Second is the descriptive power or information provided by the scale value.

## DETERMINATION OF THE ANALYTICAL POTENTIAL OF SCALES

These two aspects of determing the analytical potential of scale values require further explanation. Operational character of scale values is the ability to manipulate the values of the scale by addition or subtraction and to obtain the value of a group of values. This ability to use scale values in the generation of other scale values is very useful and a much desired characteristic of a scale. The descriptive power of the scale provides information about any individual entity in reaction to

[1]For a comprehensive study on measurement and consumer utility see [20].

[2]G.M. Lady, A Study of the Utility Concept in Economics, Report Serial T-157 (Logistics Research Project, George Washington University, 1963), p. 4.

another. The information provided by the scale is indicated by the permissable transformation which may be performed upon a scale without altering the meaning of the scale value. By this is meant the ability of the scale to provide a ranking of the differences between entities.[3]

## MEASUREMENT

Measurement is an abstraction with regard to some attribute or characteristic of an entity which may be called a dimension. The set of entities to be measured must be identified by some unambigious rule. The process of abstration is customarily, although not always, the ascribing of numbers to the entities and interpretation of the properites of the numbers as properties of the entities. The general aim of measurement is to map a set of entities on the real numbers scale in such a way that, to the greatest possible extend, conclusions concerning the relations between elements of the set of entities can be drawn from corresponding relations between their assigned numbers. The ability of numerical properties to represent real properties is called isomorphism between the numbers and entities.

## ISOMORPHISM

Isomorphism is the similarity or likeness between numbers and entities. Isomorphism is basic to the theoretical formulation possibilities of scales. The graduation qualities of the scale is a problem of accuracy. The likeness between numbers and entities is developed by the statement of formal axiomatic structures describing the nature of this relationship. Some applicable axioms are bisymetry, continuity,

[3] Ibid., p. 4.

existence, and monotonicity which express the relationships of symetry, consistancy, independence, and intransitivity.[4] The degree of isomorphism that exists between the entities and numbers should be examined before numbers are used to represent the entities. Isomorphism is the heart of measurement theory.

## UNIQUENESS OF SCALES

The uniqueness of the properties of a scale is typically characterized by the kind of transformation that may be performed upon the set of descriptive numbers.[5] Transformation is an operation upon the members of a scale that yeilds new scale values without destroying the measurement value of the scale. The interpretation and manipulation of the numbers in a scale is dependent upon the degree of this uniqueness inherent to the entities being measured. The manipulation of a scale value must be defensible as a manipulation of the entity represented. Manipulations which are not meaningful when applied to the subject of measure can not have meaning when applied to the representative numbers.[6]

## TYPES OF SCALES

There are three basic types of scales: nominal, ordinal, and cardinal. The assignment of values to entities in nominal measure implies only identification, such as solid, liquid or gas. The ordinal scale is a simple ranking of entities by equality or in-equality such as we have in a simple priority system. In utility theory, equality

[4]For additional explanation of these axioms see [20].

[5]Lady, _op_. _cit_., p. 5.

[6]_Ibid_. p. 6.

and inequality are expressed in the terms indifferences and preferences. The highest order of measurement is the cardinal scale, which has two additional degrees of order. The first cardinal scale, called an interval scale, ranks intervals between scale values as well as ranking the values, such as temperature measures. The second cardinal scale, called a ratio scale, measures some characteristic of an entity from absolute zero, incorporates the attributes of the other four scales, and has the most power to inform of the four scales. A example of such a scale would be linear measurements in inches and feet. The selection of any one of these scales is dependent upon the problem for which the scale is to be used, upon the information which is needed and on our ability to scale or measure the variables in the problem.[7]

ANALYTICAL POTENTIAL OF THE FOUR TYPES OF SCALES

The analytical potential of the four types of scales will be given only briefly. Nominal scales have no operational potential and are limited in descriptive power to identification of an entity. Thus the nominal scale will only classify an object by some property which will distinguish it from another. The ordinal scale's descriptive power is limited to comparing entities and its operational potential is at best limited. Ordinal scales will only rank entities and indicate equality or inequalities of various entities in relationship to one another. The interval scale provides the benefits of the ordinal scale and in addition provides an indication of the differences between entities. If entities can be represented by an interval scale, then there should

[7] Ibid. p. 6.

exist a unit of measure as part of the nature of the measurement. The interval between numbers is represented by a difference of these units. The interval scale can be used to derive relative measures of comparison and has very useful operating capabilities. The central difference between the ratio scale and the interval scale is the fact that the ratio scale assumes an absolute zero point while the interval scales does not.[8] The ratio scale provides the maximum analytical potential. If the members of a set can be described by the ratio scale, then the members of the set will be completed ordered such that entities, difference between entities, and the distances of entities from a absolute zero point are known and the various attributes of the numbers can be ranked among themselves. If numbers can be ranked among themselves, then an interval between entities can be compared to an entities distance from absolute zero, and the attribute of uniqueness prevails.

## THE IMPORTANCE OF MEASUREMENT THEORY

The military decision-maker, presented with many and varied alternatives, needs methods of measuring the military worth of these alternatives. The problem for the decision maker is this: Given a number of points representing alternatives which exist in a space whose dimensions are the evaluation or appraisal of the alternatives in terms of particular attributes, how are these alternatives to be ranked?[9] Improved techniques and increased knowledge in measurement theory will

[8] Ibid. p. 23.

[9] W.G. Mellon, "Priority Ratings in more than one Dimension", Naval Research Logistics Quarterly, Vol. 7 (1960), p. 513.

greatly improve military decision-making. For many years the theory of measurement was restricted to the special circumstances usually encountered in geometry, astronomy, and physics, to additive magnitudes, such as mass or electrical resistance or length. In psycho-physics, psychology, welfare economics or military worth, analytically potential scales have been difficult to develop. New mthods are being developed, however. In psycho-physics, for example, the method of "bisection" has been developed in obtaining scales for subjective magnitudes such as pitch, loudness, etc.[10] In the field of econometrics, Morgenstern and Von Neuman have developed a method of measuring subjective utility. The Morgenstern-Van Neuman method has found considerable use in the measurement of military worth. The psychologist's theory of psychometrics, mental meansurement, has found application in the development of military essentiality measures for repair parts by a questioning-mission effect technique. The measurement scales developed compare favorably with the properties of the interval scale. As these new methods of measurement are developed and find application in military decision-making, by giving better analytical scales, alternatives can more effectively be measured and compared, and improved choices made.

[10] J. Pfanzagl, "A General Theory of Measurement Application to Utility", Report Memorandum No. 5 (Princeton University Economic Research Program, Princeton University, 1958). p. 1.

[11] J. Von Neuman and O. Morgenstern, Theory of Games and Economic Behavior (Princeton: Princeton University Press, 1944).

# CHAPTER III

# UTILITY THEORY[1]

## SOCIAL CHOICE

The concept of utility may be related to the phenomenon of choice. In a capitalist demoncracy there are essentially two methods by which social choices can be made: voting, typically used to make political decisions, and the market mechanism, typically used to make economic decisions. Elsewhere in the world, social decisions are sometimes made by single individuals or small groups and sometimes by a widely encompassing set of traditional rules for making the social choice in any given situation.[2]

The last two methods of social choice, dictatorship and convention, have in their formal structure a certain definiteness absent from voting or the market mechanism. In the dictatorship, there is but one choice. In the society ruled by convention there is a common will established by the conventions; therefore, social decisions are not in conflict with individual wills involved. Choice by dictatorship and by convention can be rational, provided the individual or conventions are rational.

In a capitalistic demoncracy, social choices are made by amalgamating the tastes or preferences of many individuals, which may bring about short run irrational and inconsistent decisions. This irrationality and inconsistency is brought about by the Paradox of Voting,

[1]For two excellent studies on social value and utility theory see [1] and [20].

[2]K.J. Arrow, <u>Social Choice and Invididual Values</u> (New York: John Wiley and Sons, 1951), p. 1.

described in [1] . It is difficult to ascribe rationality and consistency to social choice made by collective methods of choice, where the wills of many people are involved, except perhaps in the long run. Before an understanding of patterns of social decision-making can be had, utmost precision and mastery in the more limited field of individual choice must be gotten. Once these are measured and quantified, methods of formally constructing a procedure for passing from a set of known individual tastes or preferences to a pattern of social choices could be developed.[3] The ultimate aim is better prediction of human behavior and better decision-making.

## INDIVIDUAL CHOICE

Habit, custom, tastes, and preference may all be considered important influences on the choice of an individual. The notion of satisfaction is a particularly important consideration in the examination of the choice of an individual. Analytically it is at present convenient to aggregate all factors contributing to the choice decision of an individual into the single concept of utility. Lady gives a primitive definition of utility as that which determines choice.[4] Be defining utility in this manner, a quality of the individual rather than an inherent quality in an object or entity is being sought. The aspect of the utility dimension which describes the individual's disposition towards an object may be called preference. An important fact to focus

[3] Ibid. p. 2.

[4] G.M. Lady, A Study of the Utility Concept in Economics, Report Serial T-157 (Logistics Research Project, George Washington University), p. 2.

upon is that preference determines choice and not the size of the number chosen to represent preference.

Individual attitudes are structured. A structured attitude indicates that in the choice of objects there exists relationships between goods and services that needs to be taken into account. These relationships can be classed as independence, complementarity, and substitutibility. Complementarity and substitutibility bring to bear the notion of a diminishing marginal rate of substitution as a propostion concerning an individuals behavior in relationship to the choice of objects. The similar relationship of internal feeling or emotion toward the consumption of goods and services is reflected in the notion of the law of diminishing rate of marginal utility. This law states that satisfaction or pleasure diminishes as more and more of the unit is consumed. The ratio scale is the only type of scale that would include information concerning the feelings of the individual as well as information concerning his choice among objects.

## MEASURING UTILITY

Folsom makes the following statement concerning measurement of utility:

> Notions of utility and worth, or value, of human actions and material prerequisities have attracted the attention of philosophers and economists in increasing measure since the dawn of the industrial era. The ideas of worth, utility, and value have proven difficult to formalize because they are not "absolute", because they have not yielded to a single scale of measure, because of countless possibilities of "exchange" or trade-off in measures of value which vary with circumstances, and because it has not been possible in most cases to dissociate moral and social "value" from material values. None the less, scientists are active in studies of worth and value theory, but in general their results are still in the initial stages of being transformed into practical tools for executives.[5]

[5] P.L. Folsom, "Military Worth and System Development," <u>Naval Research Logistics Quarterly</u>, Vol. 7 (1960), p. 501.

For these reasons the operational property of the addition of scale values to gain the scale values of the aggregate is restricted and generally not considered to be necessarily an available means of constructing a complete ordering for a utility function.[6] Only limited cardinal scales of utility have been developed. Present methodology does not permit the determining of a ration scale of utility.

The problem of how to measure utility can be approached from two aspects. First, it can be approached by the method of introspection; that is by verbal responses of individuals involved to certain questions. Secondly, utility can be measured by behaviorism, i.e. it can be measured by certain actions of the individual. These actions find their motivating force in the complicated wants and needs of the individual, which may be physiological needs or psychological needs or most probably a combination of both. The difficulties lie in properly describing the assumptions which have to be made about the motives of the individual.[7]

## BASIC ASSUMPTIONS[8]

Certain assumptions concerning individual behavior or attitudes are made in developing utility measures. First, the individual's preferences are consistent with the underlying axioms of the scale. Secondly, preferences are unchanging over a specified period of time. Thirdly, an ordinal scale or an interval scale of preference is in some manner

[6] Lady, op. cit., p. 46.

[7] J. Von Neuman and O. Morgenstern, Theory of Games and Economic Behavior (Princeton: Princeton University Press, 1944), p. 8.

[8] Lady, op. cit., p. 22.

discoverable, i.e., utilities are numerically measurable. Finally, an individual will act to maximize his preferences. By this it is meant, an individual, who has a fixed amount of money, being confronted by the prices of goods and services will, in spending this amount of money, select that group of goods and services which will give him maximum satisfaction. He prefers the chosen mixture of goods and services to any other group available to him for purchase.

## CHOICE CONTEXTS

In the measurement of utility it is necessary to take into account three separate choice contexts: certainty, when the outcome of a choice is known; risk, when a given choice implies several possible outcomes, each associated with a known probability distribution and; uncertainty, where the form of the probability distribution is unknown.[9]

## CHOICE OF A SCALE

The use of one scale rather than another is determined by the problem to be approached and not, in the case of the problem of the consumer, by whether or not emotion or behavior is to be used as a basis for constructing the scale. A few brief comments concerning the selection and use of the various scales in the measurement of utility is given below. The use of the interval scale makes no implicit assumptions about the feelings of the individuals, but instead indicates that it is necessary for the intervals between scale values to be ranked. Again, ranking of the interval values can be achieved by behavioristic or an introspective point of view. The ordinal scale may, on the other

[9] Lady, *op. cit.*, p. 6.

hand, be supported by assuming that the ranking achieved indicated a ranking of quantities of internal satisfaction.[10]

Choice of context will influence the choice of scales. Under conditions of risk, the choice of an individual does not lead to a sure outcome, but rather leads to a set of possible outcomes, each outcome associated with a known probability. In this case the ordinal scale does not provide enough information to indicate the choice of the consumer; therefore, the interval scale would be required. Under conditions of uncertainty, the ratio scale should be used.

## BEHAVIORISTIC METHOD

A behavioristic method of determining order of choice would be to present an individual an array of objects or entities to choose from. The more difficult the choice, the smaller the difference between the utilities of the objects to be chosen. Rather than showing preference for these items, the individual would be indifferent between having one or the other. An objection to this methodology is that the notion that difficulty in choice need not wholly be related to differences in utility. A second method used to order differences between utilities is inconsistency of choice. Presumably, the more inconsistent the choice between objects the more similar their utility and thus the smaller the interval between their utility numbers.[11] In both cases however, the choice difficulties may be because the decision-maker posses imperfect knowledge concerning the objects of choice.

[10] Lady, op. cit., p. 51.

[11] Lady, op. cit., p. 28.

## GAMING THEORY METHOD

The Theory of Games, formalized by Von Neuman and Morgenstern, presents a methodology by which a weak interval scale may be generalized that would indicate the choice of an individual under conditions of risk.[12] Risk in this case is defined as that choice situation where an individual is given a set of possible know alternatives, each associated with a given probability, whose sum of being realized, equals one and with the provision that a choice will lead to one of the known alternatives. Probability may be visualized in two ways, as a subjective concept more or less in the nature of an estimation or, alternatively, as a perfectly well founded interpretation as frequency in long runs.[13] Since in the Game Theory Method, probability is used in constructing an individual, numerical estimation of utility, the latter definition is used. This gives directly the necessary numerical foothold and ties probability and preferences together. Finally, the Game Theory methodology measures utility with regard to different quantities of an identical commodity, e.g., of money.

The Game Theory methodology develops the weak interval scale of utility based on an expected utility hypothesis, which is defined by

[12] For Von Neumann's and Morgenstern's development of the Theory of Games see [11].

[13] Von Neumann and Morgenstern, op. cit., p. 19.

Becker as follows:

> For each person there exist numerical constants, called utilities, associated with the various possible outcomes of his actions, given the external events not under his control. If, for a given subject, we could know the values of these constants and the ("personal") probabilities he assigns to the various external events we can, according to this model, predict his choice among any available set of actions: He will choose an action with the highest expected utility, i.e., with the highest average of utilities of outcomes, weighted by the probabilities he assigns to the corresponding events. He will be indifferent between any two actions with equal expected utilities.[14]

Using this hypothesis, the numerical utility scales are developed by interrogating the individual concerning the probability of his being indifferent between receiving a certain sum of money and in playing the game. Predictive scales of utility are developed from the outcome of these interrogations. This scale provides the information (unique up to a linear transformation) concerning the rate of change of utility with respect to changes in the quantities of goods and services.

Game Theory scales make no statement concerning the individuals feelings toward an object. Rather, they assume certain rational consistencies in his behavior, namely he seeks to maximize his expected utility, and the ability to represent behavior through the use of choice scales.

## CRITICISM OF GAMING THEORY METHODOLOGY

There have been numerous arguments and criticism against this method. The two most serious faults are two underlying assumptions made in the construction of the scales. First, it is assumed that

[14]G.M. Becker, M.H. DeGroot and J. Marschak, Measuring Utility by a Single-Response Sequential Method, Working Report Number 37 Western Management Science Institute, University of California, Los Angeles, July 1963), p. 1.

utilities of various alternatives are independent of one another and therefore have constant marginal utility. This does not take into account the law of diminishing rate of marginal utility. The second assumption is that individuals have perfect knowledge, which in most cases does not exist in the real world. Other arguments, such as an individuals unwillingness to play a gambling game because of moral reasons, the available amounts of money changing the utility function, or people being unable to deal with finely graduated probability coefficients, are leveled at the format of gaining the information necessary to construct the scale rather than the criteria for construcing the scale.[15]

One of the stronger arguments against the gaming method of determining utility has been put forward by Arrow. This argument is shown below:

> Even if, for some reason, we admit measurability of utility for an individual, there still remains the question of aggregating the individual utilities. At best, it is contended that, for an individual, his utility function is uniquely determined up to a linear transformation: we must sill choose one out of the infinite family of indicators to represent the individual, and the values of the aggregate (say a sum) are dependent on how the choice is made for each individual. In general, there seems to be no method intrinsic to utility measurement which will make the choice compatible. It requires a definite value judgment not derivable from individual sensations to make the utilities of different individuals dimensionally compatible and still a further value judgment to aggregate them according to any particular mathematical formula. If we look away from the mathematical aspects of the matter, it seems to make no sense to add the utility of one individual, a psychic magnitude in his mind, with the utility of another individual.[16]

[15]For some experimental work in Gaming Theory see F. Mosteller and P. Nogee, "An Experimental Measurement of Utility", J. Polit. Econ., Vol. 59 (1959), pp. 371-404.

[16]Arrow, op. cit., pp. 10-11.

## BENEFIT OF UTILITY THEORY TO MILITARY DECISION MAKING

The imporance of utility theory to the military is that it suggests methods of determining military worth measures to be used in decision-making. In spite of some of the weaknesses in developing the utility scales, they have proven useful and will continue to prove useful in dealing with certain military problems.

# CHAPTER IV

# MILITARY WORTH AND VALUE

## VALUE AND WORTH DEFINED

An object or entity has both worth and value. Worth is that quality or sum of qualities of an entity rendering it essential, valuable, or useful. Value is the estimated or assessed worth, usefulness, or essentiality an individual places upon an entity by itself or in comparison with other entities. Because there exists only a fine distinction between the terms worth and value, they will be used interchangeably. An individual's value judgements may be arbitrary and in a sense conventions of the time and place. Value is often influenced by the worth and imputed importance of the entity. Values or preferences of an indiviudal are described in his utility function and find their expression, in the material realm, by the goods and services which he purchases. The many social and ethical aspects affecting an individuals values will not be discussed.[1] Social value generally reflects the aggregation of the values of the individuals composing the society.

## MEASURING VALUE

Individuals and societies assess different values to different entities. This implies two very important elements. First, not all entities possess the same worth or value. Second, differing values indicate that there must be some underlying method used in measuring value.

Value measurement requires two basic questions to be answered. Who

[1]An excellent discussion on the various social and ethical aspects of value is presented in [4], pp. 404-413.

or what should be measured? How should value be measured and in relation to what? In the democratic capitalistic society, where egoistic hedonism prevails, value preferences of individuals, groups, society or the culture should be measured. Two methods of approach may be used in developing measures of an individuals values. An individuals values may be measured by introspection; i.e., values measured only by verbal responses to questioning of the individual involved. Value may also be measured by behaviorism; i.e., values measured by other types of individual action.[2] Under hedonism, value is measured in relation to the amount of satisfaction that an entity provides to an individual. Generally no absolute value prevails, only a relative value developed as entities are brought into comparison with one another.

## THREE ASPECTS OF VALUE

Values may be examined under three propositions. There may be absolute values, individual or social values, or historical value trends.[3] Absolute value is a super-set of values as opposed to values made in comparison. The absolute value may have that value by intuition or some divine Providence. If we expect the absolute value assumption, then value is given and only requires the development of some method to measure. An axiom to underlie this would be too weak for selecting values for military planning. If not given, then values are measures of certain properties of individuals or groups. In this case we must determine who or what to measure and how, as indicated in the

[2] J.F. McCoskey and J.M. Coppinger, Operations Research For Management, Vol. 2, (Cambridge: Harvard University Press, 1963), p. 408.

[3] Ibid.

previous section. If we don't take values as given and try to measure them by some method, then measurements are subject to error. A third proposition of value is that they are not given or determined by specific groups or individuals, yet are measurable by methods of science. This method generally measures trends in value, not just value itself.[4] It is a process of a series of approximation leading to truth. The implication of this last concept of value is illustrated by Churchman's statement that:

> Man not only develops in his ways of doing things, but he also develops in his interests for objectives. The true value of an objective represents the ultimate stage of this interest-development; it is never fully attained and can only be estimated...no finite set of data is sufficient either to provide the exact measure or the exact meaning of the measure.[5]

A detailed explanation of these three propositions of value is given in [4], pp. 401-413.

## MILITARY WORTH: A SUBDIVISION OF GENERAL FIELD OF WORTH

Military worth may be conceived as a subdivision of the more general field of worth and value.[6] Because of this relationship, many of the concepts developed in the general field of worth are equally applicable in the study and development of military worth measures. Some basic concepts of utility and value theory have been discussed in the preceding chapters and the first few sections of this chapter for that very reason. The military worth analyst must keep abreast of the

[4] Ibid., p. 409.

[5] Ibid., p. 410.

[6] P.L. Folsom, "Military Worth and Systems Development", Naval Research Logistics Quarterly, Vol. 7 (1960), p. 501.

literature in the general field of worth to take advantage of the advancing knowledge and technology in this area and to avoid avenues of approach that are parochial or have led to dead ends.

## MILITARY WORTH DEFINED

There is no universally applicable definition to military worth. Military worth or value may assume many definitions depending on which level in the hierarchy of the National Defense structure it is being applied and what criteria are being used to define it. Military worth may assume different definitions when considered in each of the three basic military planning areas, strategic, tactical or logistical. At the national level it may be defined in terms of contribution to winning or deterring some kind of war, or more broadly of achieving national security. In this regard, Peck defines military worth as follows:

> The peacetime value of a weapon system depends mainly upon its ability to deter other nations from going to war. In an aggregate sense, the deterrent value of a nation's weapons arsenal is relatively easy to define: it is the economic losses avoided by preventing aggression and war.[7]

At the level of the individual military decision-maker it may be described as his preference for, or amount of satisfaction he receives from having a certain military entity. In this context military worth and utility are used interchangeably. In the logistics area of military planning, military essentiality has been used to define military worth. Military essentiality is broadly defined as the importance a repair part, equipment, ship, etc., has in relation to the readiness of a unit to accomplish its missions. A mission consists of a task and a purpose; the purpose is usually the organization objective.

[7]F.M. Scherer and J.M. Peck, The Weapons Acquisition Process: An Economic Analysis (Boston: Harvard University Press, 1962) pp. 271-272.

Difficulties arise in the correlation of military worth definitions and measurement at high and low levels or in and between planning areas because of inconsistancy. These inconsistancies may be brought about by errors and inconsistancies of the military decision-makers, due to lack of adequate information and the complexity of the problem of military worth.

## CONCEPT OF MILITARY WORTH

Victory may be gained at too great a cost.[8] Immediately this brings to mind the concept of military worth or value. If the cost was too great, what would have been the better or "best" strategy to bring about victory at a lesser cost? Here, it is hoped, the military decision-maker would be able to select a strategy or a combination of strategies "best" suited to his ends on the basis of a set of relative value-graded predicted outcomes.[9] The difficulty is in quantifying and measuring these value-graded predictions. Military conflict is not deterministic and it is difficult to put the various mathematical tools into application in solving the problem. Information is incomplete, uncertain, and there is great difficulty sorting out and handling mixtures of quantitative and qualitative factors.

"National Defense costs too much". Here again, the concept of worth comes to the forefront. If this is so, then the values of our weapons arsenal must be reassessed. The importance of such assessments

[8] Folsom, op. cit., p. 502.

[9] Ibid., p. 502.

are stated by Folsom:

> The executive who is supervising system development must, therefore, weigh value and consequences and project the "military worth" of his product, as never before. Expensive undertakings face a higher risk of premature obsolescence. Potential future capabilities of the new system must be considered in value-relationship to current capabilities. The existence of constraints, particularly limits in funds, is a condition which poses sharp questions of value and military worth in respect to total cost, rate of funding, competing demands, the capabilities that will be produced by the effort, and many others...best value judgments are required from the very outset of the venture.[10]

Interest in the military worth concept has been sharpened through the emergency of appropriate analytical tools in dealing with military worth, through the identification of problems which submit, with realism, to formal mathematical treatment, and through the growing awareness of its importance.

## MILITARY WORTH AND COST-EFFECTIVENESS

There exists a need to measure the relationship of one weapons system in relationship to other weapons systems and in relation to the enemy's weapons systems. Use of the monetary criteria is too limited, since it leaves out of account the military worth of alternative defense schemes. This is not to say that cost-effectiveness studies and comparisons are not a step forward, but the methodology needs to be extended. Peck clearly indicates the usefulness of cost-effectiveness

[10] Ibid., pp. 502-503.

studies and also indicates one of their limitations:

> The methodology known as cost-effectiveness analysis provides in some cases an operational substitute for direct value measurement, given only certain decisions on broad military objectives. Cost-effectiveness techniques to estimate the incremental savings which a proposed new weapon system would afford over existing or alternative methods of accomplishing the objectives. Such savings reflect the incremental military value of the program under consideration, as long as the objective is held constant. It would appear that this approach, which essentially measures opportunity costs or avoidable costs, is a tolerable surrogate for military value estimates in development cost-quality trade-off decisions, although it is probably less satisfactory in cost-time trade-off situations. In any event, military value judgments must be and indeed are made, either explicitly or implicitly by military planners.[11]

As a further caution to stressing the monetary aspect of military decision making, Morgenstern states that:

> The first point that has to be made absolutely clear is that the economy and the economic well-being of the people are not the dominating concern. Overshadowing everything is the safety and survival of country and nation.[12]

In making rational decisions, the aspects of military <u>worth</u>, <u>cost</u>, <u>quality</u> and <u>time</u> must be weighed and integrated into the analysis of alternatives.

## NEED FOR QUANTIFICATION AND A DEFINITIVE TEST OF MILITARY WORTH

A business entrepreneur in a free enterprise can compare expected costs with expected sales and profits when he has to decide which allocation of his scarce resources is better than another. All are expressed in dollars, in other words, by a common base of numbers. The individual values are reflected and are aggregated to reflect society's

[11] Peck, <u>op. cit.</u>, p. 273.

[12] O. Morgenstern, <u>The Question of National Defense</u> (New York: Random House, 1959), p. 192.

material values in the pricing system. The market and pricing system incorporates a vast amount of information, free, that an entrepreneur needs to operate with in the complex world of today.[13]

The military decision-maker has no comparable mechanism at his disposal.[14] There is no known method of giving a numerical expression to the military worth of different weapons systems, of deploying forces to one area instead of another, or of producing more units of one weapon rather than more of another. Similarily, values attached to the capture or destruction of straits, fortifications, ships, battalions, etc., as well as what will be necessary to capture them may in reality be impossible to determine precisely.[15] Additionally, many weapons systems have not been tried. In many cases, they can not be tried. Their effects are only estimated for the future. Prospects are not certain. Therefore, weapon system's assumed military values are not certain either.[16] In any event, decisions must be made on the basis of some sort of an idea of the relative importance of the various objectives and the systems used to accomplish these objectives. Much of the evaluation consists of judgements that are neither definable nor rigorous, made by military personnel, often using procedures that are variable .[17]

[13] Ibid., p. 203.

[14] C.J. Hitch and R.N. McKean, The Economics of Defense in the Nuclear Age (Cambridge: Harvard University Press, 1963), p. 163.

[15] T.M. Whitin, The Theory of Inventory Management (Princeton: Princeton University Press, 1953), p. 205.

[16] Morgenstern, op. cit., p. 203.

[17] P. Brock, et al., "Techniques for Evaluating Military Organizations and Their Equipment", Naval Research Logistics Quarterly, Vol. 9 (1962), p. 212.

This does not imply that these subjective evaluation methods are without value, only that they are necessary. However, such procedures require systematization and substantiation through investigations of measurable quantities that can either support, extend or contradict these evaluations.

Morgenstern makes the following statement concerning the need for improved military value-assessment:

> To develop a method would be more important than to introduce some further, purely technological, advance in some weapons system. It would improve the use of all of them. Yet without having solved the question of determining the military worth of the various alternatives no convincing, rational choice can be made. Only the usual vague, intuitive appeals to strategic needs, etc., are possible.[18]

The objective is to determine the "best" weapons combination that optimizes military worth subject to the constraints of the problem. No one knows precisely how satisfaction and military worth are related to the obserable outcomes of various courses of action; however, if the objective of maximization of military worth is to be realized approximations will have to be made and quantified on a numerical scale.[19]

## MILITARY WORTH MEASUREMENT

Measuring and expressing military worth in meaningful analytical scales is a difficult problem.[20] The techniques suggested in measuring values and the propositions outlined in the second and third sections of this chapter are equally applicable in the measurement of military

[18] Morgenstern, op. cit., pp. 205-206.

[19] Hitch and McKean, op. cit., p. 160.

[20] For the development of multi-dimentional indicies of military worth see [43] .

worth. The questions, who or what and how, must also be answered in seeking to evaluate military worth.

There are many approaches in establishing military worth indicies. Two will briefly be discussed. First, individual military decision-makers military value assessments have been measured by the introspection method. The values obtained by this method are not an attempt to determine real worth, since there is, presently, no absolute numerical measure of military worth.[21] The values derived by this method are numerical values, in most cases, which are consistent with certain military opinions and decisions. The second approach is a combination of introspection and the proposition that value is measurable by methods of science as discussed under the three aspects of value.

The objective of the second approach is to be able to compute an index to serve as a figure of merit or military worth measure for particular means of accomplishing a given mission or objective. Instead of looking to introducing additional attributes, perhaps leading to a vote, it tries to establish a preference as an explicit function of the original attribute.[22] Such will be done through use of an index which will be a single number formed by aggregation of the original measures. There exists some collection of numerical measures relating to performance of a mission. From this collection by means of some process such as selection or combination, it is possible to derive the basic measure on which an index will depend. The measure should reflect some funda-

[21]G. Suzuki, "Procurement and Allocation of Naval Electronic Equipments", Naval Research Logistics Quarterly, Vol. 4 (1957), p. 3.

[22]Survey of Command Logistic Problems, (Logistics Research Project, George Washington University, 1963), Report Serial T-161, p. 3.

mental attribute, the more basic the better, since otherwise an essential index could hardly be expected to result.[23] Also, the basic measure need not itself amount to an overall figure of merit since this would make the index unnecessary.

Military worth may also be measured, not as an index or separate value, but by developing several value measures. Such a technique is used in missile systems evaluation. Five value factors are compared when evaluating missile systems: costs, cost on station and survivability, probability missile gets to target, target value, and some unmeasurable subjective factors. With more than one criterion of evaluation, these criteria may be combined with weighting functions to obtain a composite criterion. These weighting functions may be based on probabilistic distributions and thus yield expected value measures. Various approaches and methods can be used in measuring military worth measures depending on the problem to be approached and the amount of information and operational characteristics the measure must provide. Two separate authors writing in the field of military worth have clearly indicated this:

> The proper approach in designing numerical indicators to assist us in military computation is to first decide which criterion these methods of establishing the worth scales should meet and to then design them accordingly, since the degree of measurement involved in military-worth studies is necessarily limited.[24]

> Clearly, there is no all-purpose criterion, for the appropriate test depends upon what alternatives are open to the decision-maker, upon what aspects of the situation must be taken as given, and even upon what kind of measurements are feasible.[25]

[23] Ibid.

[24] W.G. Mellon, "Priority Ratings in More than One Dimension", Naval Research Logistics Quarterly, Vol. 7 (1960), p. 525.

[25] Hitch and McKean, op. cit., p. 175.

In succeeding chapters several different methods of developing military worth measures will be discussed in realtion to the particular problem and the needed value measure.

## MILITARY WORTH MEASUREMENT ERRORS

The real world is non-simple, non-linear, probabilistic, dynamic, conservative, stochastic and/or irrational. Many of the assumptions that are made in military worth theory are simplifications that are not consistant with the real world; therefore, value and worth measurements are subject to error. To make favorable comparisons of alternatives, judgements on the value of these alternatives and the risks involved must be made in relation to themselves and in relation to the estimated capabilities of the enemy. In estimating values, errors of estimates must be taken into consideration. Other causes of possible errors are inconsistency between the correlation of high and low level military worth, inconsistance in the tests or criteria used to measure worth, the effect of interdependencies or spillovers when making evaluations at lower levels, intangibles, and finally the problem of dealing with time and its associated uncertainties. Even though these error possibilities exist, it is still the aim of the structured method to quantify military values and to make them objective, so they can be predictive, descriptive or optimized. At least trends can be seen and measured. The measure may not be exact or have exact meaning but the trend can be shown. It can be seen if we are moving in the right direction. Rather than the absolute or intrinsic worth of an entity we may only be able to measure the military decision-makers interest or utility in an item.

## MILITARY WORTH APPLICATIONS

Numerical measures of military worth have many advantages and uses. One of the most important advantages is that symbolic measures can be manipulated by mathematical formulations. Mathematics is the only language that can clearly, rigorously, and economically prove the truth of the results stated verbally in the main body of the text. Systematic measures of military worth offer these additional advantages: provides an objective basis for decisions, takes advantage of the scientific attitude in the solution of management problems; and, through disciplined observation and rigorous proof, may discover new facts and relationships which will provide new dimensions in decision-making. Military worth indices can be put to use in many areas, help establish priorities and direct effort to real problems, help in the allocation of scarce resources judiciously, help in the development of strategies needed for the deployment of these resources to achieve maximum results, and help with the tremendous problems of uncertainty and unpredictability which can not be solved solely on the basis of experience.[26] Succeeding chapters will discuss some theoretical and empirical research dealing with the derivation of military worth measures, application of the measures in decision problems, and general military decision problems which may profitably use military essentiality measurements.

[26] For the development of a mathematical technique of selecting that weapon system from a class of weapon systems with a fixed cost, which would maximize expected military utility see [40] .

## CHAPTER V

## GENERAL MILITARY DECISION PROBLEMS AND MILITARY WORTH

### I. INTRODUCTION

The development and measurement of military worth and value promotes rational and consistant judgements and provides additional insights into the variables affecting military decision making. It is the purpose of this chapter to show some derivations of military worth measures and their profitable application to general military decisions. Three general problem areas are covered; weapon systems, equipment and operations, and military control systems. As in the last chapter worth and value will be used interchangeably.

### II. MILITARY WORTH IN RELATION TO WEAPONS SYSTEMS

The Problem

Peck makes the following statements concerning the problem of military value:

> We are thus confronted with the problem of military value; that is, with the need to rank the various time-quality-cost points of out weapon system development possibility map in terms of their relative military value.[1]

To accomplish this ranking it will be necessary to formulate a military value function reflecting this relativity notion in conjunction with corresponding possibility curves of time, cost, and quality associated with each weapon system. This step is necessary if we are going to make useful comparisons of alternative weapons systems and decide upon courses of action. The goal is to maximize estimated military value relative to

[1] J.M. Peck and F.M. Scherer, The Weapons Acquisition Process: An Economic Analysis (Boston: Harvard University Press, 1962), p. 271.

estimated development costs. Military value in this case is defined broadly in terms of the contribution a weapon systems makes to the maintenance of peace or the prosecution of warfare.[2]

Military Value Functions

Peck has proposed the construction of a military value function based on a comparison of the quality of one nation's weapon system relative to the quality of its rival's systems.[3] This is based on the concept that the military value of a weapon system depends upon the quality of counterpart weapons possessed by the enemy.

Peck's hypothetical military value functions, shown in Figure 1, page 53a, are built up from more elemental assumptions about the value of qualitative parity and the rate at which enemy capabilities are expected to advance.[4] In each of the graphs shown in Figure 1, the abscissa measures the quality of the rival's systems. A zero reading indicates that the first nation's weapon system is qualitatively equal to the weapons of its rival, i.e., qualitative parity prevails. Positive readings on the quality scale reflect varying degrees of qualitative superiority and negative readings, varying degrees of qualitative inferiority.[5] Quality values in excess of plus one reflect excess weapon quality, or an over kill capacity.

The ordinate measures military value. The scale 0 to 100 was arbitrarily chosen. Any set of numbers would have been appropriate,

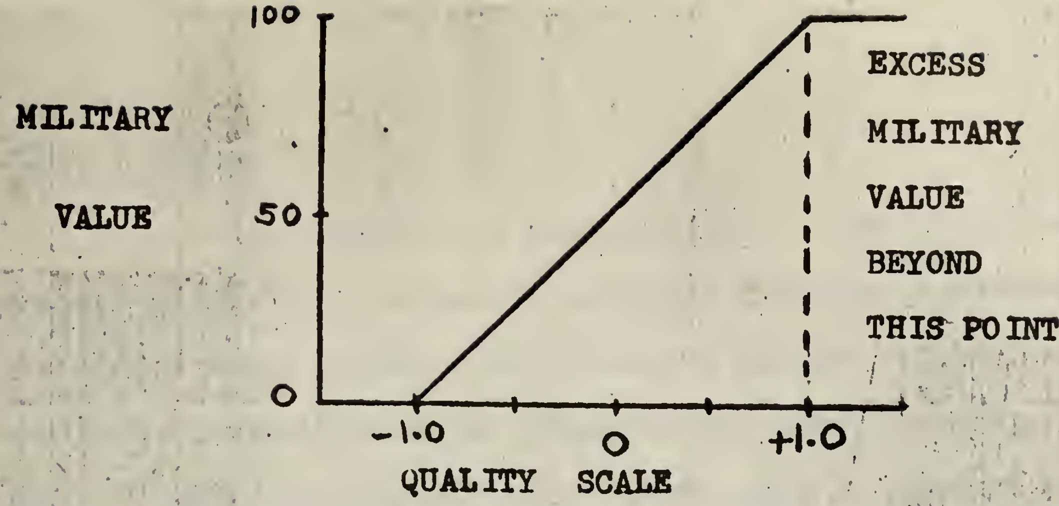
[2] Ibid.

[3] A detailed development of the contruction of the military value function may be found in [7], Appendix A, pp. 632-638.

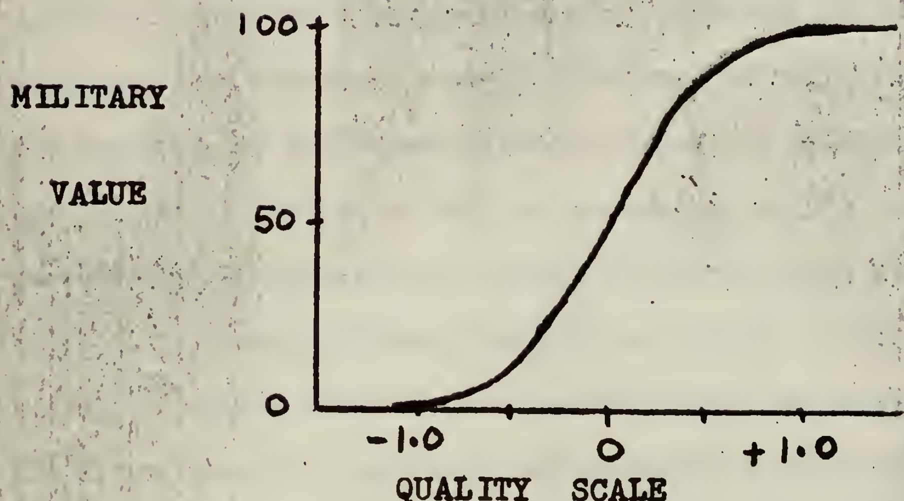
[4] Peck and Scherer, op. cit., p. 632.

[5] Ibid., p. 632.

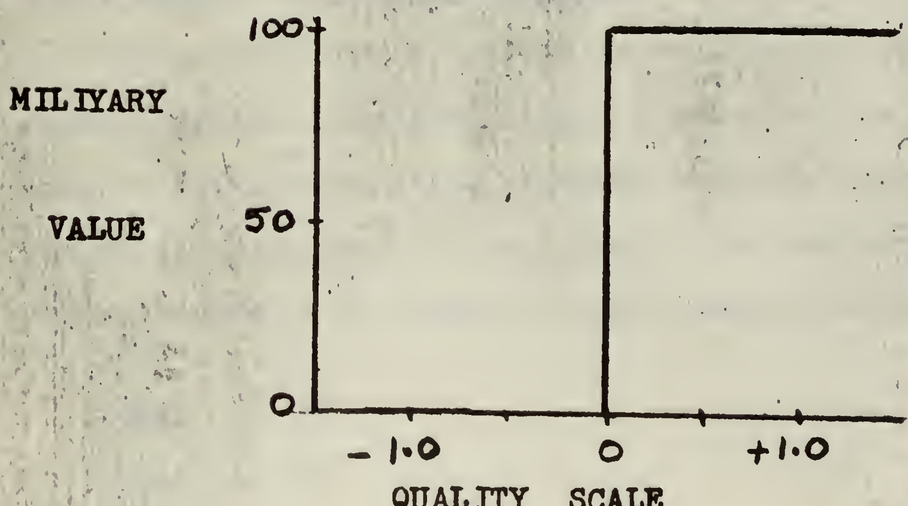
depending in practice upon the absolute payoffs associated with varying degrees of success and failure in combat. Total unsuccessful combat operations equals zero. Total successful combat operations equals one hundred.




A LINEAR PARITY FUNCTION




A CURVILINEAR PARITY FUNCTION




A TWO-VALUE PARITY FUNCTION

FIGURE 1
CONSTRUCTION OF MILITARY VALUE FUNCTIONS

Parity Functions

Three parity functions are shown in Figure 1. The linear function indicates a straight line quality comparison of disparity between the two nations weapon systems. The curvilinear function reflects that qualitative inferiority can be off-set to some extent by quantity, tactics, etc., but that such trade-offs become increasingly uneconomical as the quality disparity increases. The two-value parity function demonstrates a case when the slightest quality disparity between rivals is militarily decisive. This third parity function illustrates two important points. First, in some instances a small difference in quality of a weapon system can mean the difference between success and failure. Secondly, we must diversify weapons so that no one weapons program spoils the difference between success and failure or between peace and war. As can be seen, the shape of these function is critical in the determination of military value measures. Peck states that the shape of the parity functions cannot be specified further without additional empirical data on the consequences of various quality advantages in combat and on the rate at which an enemy is improving its weapons capabilities.[6]

Parity Function and the Time Dimension

The parity functions describe the relationship between two variables, relative quality and military value. A third variable, time, can be added by combining the parity functions with some data on expected enemy qualitative capabilities over time.[7] The introduction of this additional dimension is necessary because a weapon system of any given

[6] Ibid., p. 285.

[7] Ibid., p. 634.

quality will provide one level of effectiveness relative to the enemy's increasing capabilities is constantly decreasing.[8]

Priority Ladders

Weapon programs can now be ranked on a priority ladder according to their net military value as obtained from the military value function. From this priority ladder procurement programs can be established. However, working with priority ladders in practice is extremely complicated, since the exclusion of marginal programs from the procurement list may influence the military value of programs still on the list, causing readjustments in the individual program optima and possibly a further change in the acceptability of programs at or near the margin.[9] Given the interreactions between programs, setting individual program and overall defense budgets becomes a complex general equilibrium problem.

Benefits To Be Derived From This Model

An intuitive grasp of even extremely simple problems of weapons selection and procurement is beyond the power of most humans. The model provides a systematic method for calculating the effects of several variables, bringing explicitly to light assumptions underlying the analysis, and providing insights into the problem. Insights have several values. First, they give a clearer perception of the trade-offs made in weapons decisions. Second, the explicit recognition of these trade-offs in actual program decisions may provide substantial benefits in terms of improving the allocation of national defense resources.[10] Finally,

[8] Ibid., p. 271.

[9] Ibid., p. 285.

[10] Ibid., p. 286.

calculating military value on a parity basis over time leads to the important conclusion that the United States (as a nation whose values usually preclude aggression) must be prepared for the worst at all times by having a diversified inventory of weapons as technically advanced as possible.[11]

## III. MILITARY WORTH IN RELATION TO EQUIPMENT AND OPERATIONS

### Military Value in Relationship to Military Objectives

Whitin has postulated another method of attaching military values to equipment in relationship to military operations and missions. It is based on the intimate and intricate relationship that exists between military strategy and military value.[12] In Whitin's system knowledge of the relative importance of certain objectives combined with a careful analysis of strategies available to both one's own forces and the enemy makes possible a formal evaluation of the worth of items of military equipment in many situations.[13] This analysis of the strategic aspects of the situation must precede the assignment of a complete set of military values to the various equipments.

### Game Matrices

The type of formal analysis used in this case is that provided by VonNeumann's and Morgenstern's gaming theory.[14] Game matrices are developed based on various sets of assumptions concerning the relative

[11] Ibid., p. 294.

[12] T.M. Whitin, The Theory of Inventory Management (Princeton: Princeton University Press, 1953).

[13] Ibid., p. 190.

[14] J. VonNeumann and O. Morgerstern, Theory of Games and Economic Behavior (Princeton: Princeton University Press, 1953).

importance of objectives and opportunity costs. Opportunity cost is defined here as the cost of foregoing of planes, tanks, or some other items of equipment for additional items such as ships. The difficulty arises here in explicitly stating the relative importance of objectives or missions before military value and subsequently strategies and production plans are chosen. In the usual process of decision-making these assumptions never have to be explicitly stated, yet they must be made implicitly or the decisions could not be made.[15] Having established the game matrices, parameters can be varied to determine the effect on the mission or objectives, military values assessed, programs evaluated and courses of action chosen.

Micro-and Macro-Military Values

Here as elsewhere, the determination of micro-and macro-military values remains. It is succinctly stated by Whitin as follows:

> The problem that remains unsolved here, as in other aggregative economic models, is whether the system can be reduced to manageable size and still describe the significant relationships between the important variables of the problem. Macro-economic problems have to a large extent been neglected in research in game theory, a micro approach to games being in general use. Yet, if game theory is to be of use on a national economic level, the problem of constructing manageable yet realistic models must then be of extreme importance.[16]

The aggregation of micro-military values to obtain macro-military values is complicated by the many interfaces and interrelationships in and among weapons systems. Complementarity exists between weapons. As a result, incremental military value calculations for one weapon system run the risk of error due to changes in other programs.[17] Similar

[15] Whitin, op. cid. p. 205.

[16] Ibid., p. 207.

[17] Peck and Scherer, op. cit., p. 283.

relationships exist between both the cost and quality dimensions which further increase the complexity of the problem

## IV. MILITARY WORTH AND EXECUTIVE SYSTEMS

### Need For Executive System Evaluation

Captain P.L. Folsom has pointed out the need for evaluating and ranking differing military control systems by their military value.[18] Military control systems are defined here as those executive systems consisting of central computing elements which are connected to communication circuits of the teletype variety and to displays which show information in symbolic or alphabetic-numeric form or which provide printed data. The need for evaluating the military worth of these executive systems was stated as follows:

> The existence of constraints, particularly limits in funds, is a condition which poses sharp questions of value and military worth in respect to total cost, rate of funding, proportions and shares of resources in relation to other competing demands, the capabilities that will be produced by the effort, and many others.[19]

### The Problem

Mellon indicates that, stated in its simplest terms, the problem of valuing the executive systems is this: given a number of points representing atternatives which exist in a space whose dimensions are the evaluation or appraisal of the alternatives in terms of particular attributes, how are these alternatives to be ranked?[20] The static

[18] P.L. Folsom, "Military Worth and Systems Development", Naval Research Logistics Quarterly, Vol. 7 (1960), pp. 501-5011.

[19] Ibid., p. 505.

[20] W.G. Mellon, "A Selected, Descriptive Bibliography of References on Priority Systems and Related, Non-Price Allocations", Naval Research Logistics Quarterly, Vol. 5(1958), p. 515.

problem is difficult enough, but the additional dimension of time must be considered as it exerts an ever-increasing influence on the worth of any system.

Military Value Criteria

Folsom suggest a subjective evaluation based on certain value criteria, rather than a rigorous mathematical derivation of military value. To assess and compare the military worth of executive systems, he has recommended that different systems be compared with one another on various criteria of desirability, such as cost, dependability, maintenance, feasibility, versatility, uniqueness, and so on.[21] This illustrates that military worth can be derived by many methods and take many forms.

[21] Folsom, op. cit., pp. 10-11.

CHAPTER VI

# MILITARY WORTH AND LOGISTICS

## I. INTRODUCTION

### Military Planning Areas and the Logistic Problem

Military planning covers three basic areas: Strategic, tactical, and logistical. Strategic planning is long range, board planning and execution. Tactical planning deals in direct enemy contact and its immediate operations support. Logistical planning is concerned with all aspects of military support. There exists a close interelationship between these three areas. A logistic operation consists in the supply of definite quantities of physical means and services for activities that, according to their missions, consume these means and services in order that the activities be maintained at particular present or expected future rates.[1] Morgenstern makes the following statements concerning the logistic program and the feasibility of certain solutions to it:

> Logistic problem is to identify in detail expected requirement. After the identification has taken place, the quantities, corresponding to the rates of the various component phases of the activity, have to be computed in such a manner as to make the entire supply plan an "optimum" (e.g., minimizing time, or costs, or tonnage used, etc., or combinations of these), under the constraint that the desired rates should be met-within stated time limits-with some specified probability. The computation will show whether the activity can actually operate, i.e., whether its operations are feasible at the desired rates.[2]

[1] O. Morgenstern, "Note on the Formulation of the Theory of Logistics", Naval Research Logistics Quarterly, Vol. 2 (1955), p. 130.

[2] Ibid.

## Material Logistic Commodities Defined

Material logistic commodities may be defined as the following basic logistics items and functions: general supply items, medical supplies, technical repair parts, fuel, ammunition, and the maintenance and repair functions. As in the case of any logitic commodity, there are problems of estimating pure requirements; determining best or at least acceptable stock levels and resupply requirements to meet strategic and tactical needs; identification of constraints and their explicit inclusion in the determination of stock levels; the evaluation of strategic and/or tactical capabilities in light of commodity availability, etc.[3] The general problem areas are very similar if not identical over all commodity areas; however, some specific and detailed problems vary from one commodity to another.

## Requirements Determination (Deterministic Approach vs. Probabilistic Approach)

Determination of requirements is at present based on a deterministic approach rather than probabilistic approach. Current methodology uses the three factor method shown in Appendix C, originally developed by the Logistic Research Project, George Washington University.[4] The Three Factor Method is a device used in logistics planning which includes a systematic format with compiled and refined planning factors for its use, and which makes explicit quantitative use of command judgement both in estimating requirements and in transmitting these estimates to other echelons.

[3] Logistics Research Project, George Washington University, Survey of Command Logistics Problems (Report Serial T-161, 1963), pp. 1-2.

[4] C. Stein, "Briefing on the Logistics Research Program of the Navy", Naval Research Logistic Quarterly, Vol. 5 (1958), p. 227.

The Three Factor Method is not a good model for determing requirements. The method does not consider the relative importance of different commodities, constraints (such as cost weight, space, etc., which depend on the context of the problem and objectives) of stocking various commodities, and no reflection of size of the variance or deviations from the expected requirement for each commodity are provided for. Additionally, uncertainty associated with almost all logistics problems is not adequately provided for in the Three Factor Model. If "best" stock levels are to be determined, the concept of military worth and risk and their associated measurement's must be considered. A suggested factor method of dealing with these problems is shown in Appendix D. For convenience this method will be called the Four Factor Method. Losses are associated both with under and overstocking. Understocking has losses reflecting a strategic value or military essentiality. Overstocking has similar losses associated with it due to constraints of the problem, such as funds, space, weight, etc., which might otherwise have been used in providing other essential commodities The Four Factor Method develops these values. The stocking objectives for the basic commodities may then be to minimize an expected loss function which includes losses due to understocking and overstocking and the associated probability of each.[5] Further complications come from different kinds of ships, different kinds of missions, usage rates, initial outfitting and reorder quantities and points, substitution possibilities and trade-offs, resupply system requirements, stock levels, and procurements.

[5] Logistics Research Project, op. cit., pp. 16-17.

Role of Military Worth in Logistic Planning and Requirements-Determination

Military worth or essentiality plays an important role in logistic planning and requirements determination. The remainder of this chapter will deal with some specific military logistical decision problems which may profitably use military essentiality measurements in their solution. The basic areas covered will be priority indicators, allocation of equipment, inventory control, and maintenance of allowance parts lists.

## II. PRIORITIES

Basic Problem of the Logistics System

A basic problem of the logistics system is clearly defined by Mellon as follows:

> Among the problems encountered in the design of an optimal military supply system, the question of an efficient priority or allocation system looms as one of major importance. This has been generally recognized by serious students of military supply, since the breakdown of priority systems has proved a major source of difficulty to the military in past emergencies.[6]

Priorities can be taken to mean all indicators of relative desirability or preference no matter what degree of measurement they contain-that is, whether they represent a simple ordering of alternatives, an ordering on the simple or compound distances between alternatives, or a numerical scale (ordinal or cardinal) which is applied to the alternatives. A pure priority system is one which has no quantitative restrictions on the use

[6] W.G. Mellon, "A Selected, Descriptive Bibliography of References on Priority Systems and Related, Non-Price Allocations", Naval Research Logistics Quarterly, Vol. 5 (1958), p. 17. In addition to providing a comprehensive bibliography on the priority problem, Mellon also auggests a method for the combination of money and military worth or utility of projects within the frame work of the theory of games in dealing with priority and allocation problems.

of the priority indicators. In this section preference systems with a quantitative element will be referred to as allocation schemes and preference systems without quantitiative elements will be referred to as priority schemes.[7]

Purpose of Preference Systems.

The purpose of any preference system is to provide a method of more efficiently utilizing scarce resources. To quantify preference systems through the use of military worth indicies would help to better the allocation of resources. Young stresses the importance of such quantification in the following statement:

> An optimum distribution of materials can be achieved only through some quantitative system of allocation. Therefore, to insure that all direct and indirect resources are used in the most efficient manner, some quantitiative elements must be introduced into the priority scheme. The quantitative allocation is necessary and sufficient for the insuring of the optimal utilization of all resources.[8]

Less than optimal delivery detracts elsewhere from the system. Young goes on to state.

> If we can now demonstrate that there must be a quantitative element in the solution of the problem of allocating the direct resources of the system, we will have shown that any system of (non-quantitative) priorities is inadequate for the task of controlling resource utilization; whether one approaches the problem from the side of direct or indirect resources.[9]

Preferences Systems and Military Worth

Preference systems and military worth are inextricably entwined. By using military worth measurement techniques a weak interval scale

[7] W.M. Young, "Priorities in the Naval Supply System", Naval Research Logistics Quarterly, Vol. 1 (1954), p. 19.

[8] Ibid., p. 21.

[9] Ibid., p. 19.

of preference can be developed. The main interest, rather than optimization, which may not be possible with the present state of the art, is improvement in the handling of military logistic problems.

Ranking Alternatives

Military Logistical problems have various alternative approaches, whose payoffs are not single values, but a set of vectors. It is necessary to rank these alternatives by some degree of measurement. The problem is to rank alternatives represented by a number of points whose dimensions are the evaluation or appraisal of the alternatives in terms of particular attributes.[10] Mellon states that just as the number of pieces of information necessary to yield a complete order increases rapidly as the number of dimensions and the degrees of measurement in each dimension increases, so does the strength of the criteria needed to obtain a complete order of the alternatives.[11]

Priority Preference Schemes

Measurement and development of priority schemes using military worth scales, at least to the order of ordinal ranking, can be developed by the method of introspection. By direct questioning of competent personnel in relation to the effect alternatives have on a mission, a measure of the relative distances between the attributes of alternatives in particular dimensions can be obtained. Care must be taken in attributing to these numerical scales more information than they really possess. Ordering does not, and can not, establish a continuous meaningful numerical scale for the alternatives; meaningful in

[10] Mellon, op. cit., p. 515.

[11] Ibid.

the sense that it can be said that one alternative is such and such a percentage greater than another. Ordering will indicate a single "best" alternative from a group and prove satisfactory for use as a priority preference scheme.

Allocation Preference Schemes

A method of developing allocation preference scales reflecting military worth of various components was suggested by Whitin in which it is imagined a military game exists in which certain of our forces are opposed to forces of the enemy.[12] The value of the game to us can be calculated, as well as the additions to this value which result from having additional forces in action. Thus we have a numerical measure of the military value of a particular weapon or unit in a particular position which was directly derived, rather than having been determined by the question method and which can be used to guide civilian production, to determine the relative emphasis to be placed on the production of various sorts of weapons, and so on.[13] Little can be said about the solution of the game by mere orderings of objectives by the competing parties. But a comparison of the sensitivity of the outcomes of the game to changes in the matrix of coefficients compared with the degree of measurement which we possess on the ranking of alternatives by the competing parties may yield us important results.[14] The values, in terms of which maximization of results or minimization of cost is to be accomplished, lead to the establishment of allocation preference schemes

[12]T.M. Whitin, The Theory of Inventory Management (Princeton: Princeton University Press, 1953).

[13]Mellon, op. cit., p. 525.

[14]Ibid., p. 526.

for actions and sequences of actions (operations) within the logistical organization.

A Precaution

Since priorities can be set and sometimes have to be set simultaneously at different levels of the heirarchy, contraditions and inconsistency can easily develop.

## III. ALLOCATION OF EQUIPMENT BY MILITARY WORTH INDICIES

Allocation Problem

The allocation or assignment problem is one of the more important logistical problems requiring solution. Aumann states the general allocation problem briefly as follows:

> We are given a system with a number of vacant positions and and equal number of available parts. We know how well each part performs in each position; we wish to assign the parts to the position so that system performance is optimized. Applications range far and wide, from employment, to aircraft assignment, to naval overhaul programs.[15]

We shall concern ourselves with the specific problem of procuring and allocation of electronic equipment for ships. The problem is complex and involves hundred of ships of various classes and many available types of equipment. All kinds of complex relationships exist within and between the ships and the equipments. Because of the expense and dangers involved, haphazard or inefficient allocation plans should be replaced with a more systematized approach. A systematic analytical technique for obtaining acceptable allocation plans has been developed by Aumann and others working for the Princeton University Research Team.

[15] R.J. Aumann and J.B. Kruskal, "The Coefficients in an Allocation Problem", Naval Research Logistics Quarterly, Vol. 5(1958), p. 111.

Only a brief discription will be given. For a more detailed presentation see [26], [27], and [57].

Basic Concept of Aumann's Model

The basic idea of this model is that values or weights are assigned various factors and by combining these weights a numerical military value coefficient is developed for each possible way to assign each available equipment model.[16] The method of assigning equipment models is varied until the sum of weights corresponding to the assignments was maximized by use of linear programming techniques.

The task of solving this large complex allocation problem is considered to be composed of two separate jobs: the combinatorial or mathematical job and the naval judgment job. The method does not replace qualitative naval judgement, but simply finds a more effective way of using it.[17]

Over-all Military Worth Index and Position Factors

The development of acceptable allocation plans gives rise to the need to develop an index which combines the variables and reflects the value of allocating the various pieces of equipment to certain ships or positions. The index is called the over-all military worth index. To develop this index and to reflect the complex interrelationships between positions, three basic notions or position factors were used. The basic notions are priority (MIP Weight), state (Utilization of

[16] J.W. Smith, "A Plan to Allocate and Procure Electronic Sets by the Use of Linear Programming Techniques and Analytical Methods of Assigning Values to Qualitative Factors", Naval Research Logistics Quarterly, Vol. 3 (1956), p. 155.

[17] Auman and Kruskal, op. cit., p. 133.

Features Weight), and goodness (Improvement Weight).[18] Priority refers to the intrinsic importance of the mission which a position is to fulfill. State refers to the model that is already installed in the position in-question. Goodness refers, roughly speaking, to the suitability of the various models to the position inquestion.

Derivation of the Over-All Military Worth Index

An elementary description of how the over-all military worth index is derived follows. The MIP weight is developed by use of a directive from Chief of Naval Operations, called the Material-Improvement-Plan, and by use of a rank-ordering decision technique of questioning a board of naval officers. From these decisions a mathematical function is developed by which a quantitative value for military worth is determined. The concept of goodness is in reality associated with pairs consisting of a model and a position, rather than just with positions.[19] The improvement weights of the goodness factor are developed by a questioning technique requiring only a yes-or-no decision from an officer, or a board of officers, responsible for making allocation decisions.[20] Questions must be phrased as realistically as possible to present actual situations which the Board can readily picture, so as to make it as easy

[18] R.J. Aumann, "Assigning Quantitative Values to Qualitative Factor in the Naval Electronic Problem", Naval Research Logistics Quarterly, Vol. 6 (1959), p. 2.

[19] Ibid., p. 3.

[20] Experiments showed that inconsistencies in answers of the Board were of a very minor nature when aggregating results. One of the basic assumptions in this method is that it is assumed you can go from small allocation problems to more complex allocation problems by a mathematical function. For additional assumptions see [26] and [27].

as possible for the Board to consider all relevent factors in arriving at a decision. Decisions are made in response to hypothetical allocation problems of a very small size, usually involving no more than two sets of electronic equipment and two possible ships to which they could be assigned. Because of the small size of the problem these officers will be able to reach a decision solely on value judgments, experience, and knowledge. The utilization of features weight is obtained in a similar manner based on models of equipment already installed in the position before contemplated allocation, but because of practical and theoretical objections it is not included in the formulation of the over-all military worth index.

The over-all military worth index is developed by multiplying the MIP Weight by the Improvement Weight. The multiplicative function is used because it is better suited for equipment assignment. If the additive function were used, it would develop that if a very valuable piece of equipment were assigned to a worthless operation, the value of this assignment would be the value of the equipment itself, whereas the assignment should be valued, zero. The process of multiplication, on the other hand, introduces the concept that the value of the equipment and of its location have special internal relationships.[21]

Computation of An Optimal Assignment

The indicies thus developed are used as matrix coefficients in the computation of an optimal assignment problem by linear programming, where constraints are imposed by the number of each type of equipment which is on hand and/or may be purchased out of a limited budgetary

[21]Aumann, op. cit., p. 4.

appropriations. Aumann proved by experimentation that using this method developed an allocation plan that was deemed superior to the one that had been obtained by purely subjective hand methods.[22]

Conclusion.

Subjective problems of the kind considered here can have no unique correct solutions. The technique outlined in just a way to go about finding acceptable allocation plans. The purpose of the method described is not to replace the system of military command by a mathematical system; it is to transform a command decision which, because of its enormous complexity, must now be made on a largely haphazard basis, into a set of less complicated command decisions, each of which can be decided intelligently on the basis of the military judgment and experience of the deciding officers. Thus quantitative decisions on a high level are based at least in part on subjective qualitative decisions on lower levels.

## IV. INVENTORY CONTROL

Inventory Control Problem

The inventory control problems facing the Department of Defense are knotty problems and in many cases have no well-defined solution. Whitin describes the nature of the problem as follows:

[22] Aumann and Kruskal, op. cit., pp. 122-123.

> "These problems, aside from being more complex than those encountered by the ordinary entrepreneur, are also considerably more difficult than those met by most other types of non-profit organizations. The extreme uncertainty of the situations that may arise, with respect to time of origin, duration, and even the nature of events, is almost without parallel in other enterprises, institutions, and agencies. There are intricate interactions of the decisions and these interactions will themselves vary greatly with the assumptions made as to the nature and timing of future events."[23]

The inventory control problems of the military are complicated further by the size and complexity of the military organization, by the tremendous number of items being managed and by the extreme volatility of the demand (caused by changes in enemy and own strategies, changes in quantity and quality of equipment, etc.)[24].

Preceding the solution to these problems is the decision of what is to be maximized. It can be stated that the Department of Defense desires to maximize the probability of victory or to maximize the deterrance of war, although such statements have little meaning except when considered together with the cost aspects. Before any important military decisions on inventory levels are made, certain basic assumptions must be made about the probability of war, the time and duration of the war, and the probable location and nature of the war.[25]

Objective of the Navy Supply System

The first step in the solution of the inventory control problem is to state the objective. Mills indicates that the objective of the supply system of the Navy must be the objective of the Navy; improvement in the

[23]Whitin, op. cit., p. 165

[24]Ibid., pp. 166-168.

[25]Ibid., p. 170.

capability of the Navy to destroy enemy targets in war.[26]

Readiness and Its Affect on the Capability of the Navy

One of the essential elements in the capability of the Navy to destroy enemy targets in war is the readiness of weapon systems. Readiness of equipment within the weapon system depends on the reliability and maintainability of the equipment.[27] Reliability is a function of design, and maintainability is a function of both supply and maintenance. Thus, if important items of equipment are not available when needed, the capability of the Navy may be greatly reduced. Availability of essential equipment has two aspects, i.e., it may not be available because of breakdown, or it may not be available because it is located at other than the requiring activity. The lack of immediate or extremely rapid accessibility of some items of military equipment or repair parts could in some cases be as bad as its non-existence and could cause consequences of an extremely grave nature.[28].

Echeloning of Supply Support and Factors Affecting It

The capability of the Navy could be improved by proper echeloning of the material inventory. This is true because the closer an item is to the end-user, the less elapsed time there is in filling the user's order, consequently there is an increase in readiness. From the point-of-view of a ship, the levels of supply support, proceeding away from the end user in time, are: on board support, mobile support, advance

[26]H.F. Mills, "Let's Cut Out the 'Sales' Talk", Newsletter (October 1962), p. 8.

[27]H.F. Mills, "What is the Logic in Logistics", Newsletter (February 1963), pp. 20-23.

[28]Whitin, op. cit., p. 173.

base support, Navy Retail Support, Defense Supply Agency Support, and finally manufacturer support.[29]

There are several interrelated factors in addition to time affecting the level at which supply support is given. The first two factors are shelf-life and obsolescence. The next factor is the need for dispersion of military supplies to reduce vulnerability to attack. Another factor is the usage rate. Generally, the higher the usage rate of an item the closer to the end user should be the inventory support. Another factor is the cost of the item in inventory. Budget constraints improse restrictions on the amount of items that can be held in inventory. The final factor is the cost of depletion, i.e., the cost of not having an important item of equipment available when needed. If it were possible to develop cost of depletion and the probability of depletion then optimal inventories, thus increased readiness, could be developed by equating carrying charges on the marginal unit of inventory of each item to the probability of depletion multiplied by the cost of depletion.[30]

Cost of Depletion

Cost of depletion brings into the inventory problem the concept of military worth or value. Whitin indicates that even a rough estimate of military worth and cost of depletion would improve inventory control:

[29]Mills, "Let's Cut out the 'Sales' Talk", op. cit., p. 10.

[30]Whitin, op. cit., p. 186.

> To calculate the costs of depletion, much more would have to be known about the problem of military values, but the present system could probably be improved by dividing items into only a few major classes with varying importance attached to depletion. For example, goods might be divided into categories where depletion was of vital importance. Probability figures could then be assigned to each of these major categories, reflecting to some extent these varying degrees of importance. The introduction of even such a crude system into the Navy would certainly lead to the establishment of inventory levels more in accordance with the strategic importance of various items.[31]

Failure to do even this rough approximation of the importance of inventory items is to implicitly postulate that all items in an inventory system are of equal worth under all situations.[32] Because of the very close connection between the inventory problem and the problem of military worth or strategic value, there exists a need for a concept and measurement of military worth.

Research Projects Into the Development of Military Worth Concept

A major portion of the research into and information developed on the concept and measurement of military worth in the development of allowance lists has been by the Logistic Research Project, George Washington University, under the supervision of the Bureau of Supplies and Accounts. The title of the program is Allowance List Test Program (ALTP). Past orientation of most of the effort has been the problem of logistics support for small independent combatant units (e.g. submarine, ship, or aircraft squadron). A complete review of the work of ALTP is beyond the scope of this paper; however, some of their conclusions and their basic procedures in the application of military worth measures

[31] Ibid., pp. 186-187.

[32] H. Solomon, "The Determination and Use of Military Worth Measurements for Inventory Systems", Naval Research Logistics Quarterly, Vol. 7 (1960), p. 529.

will be discussed. A comprehensive review of the projects in this area is available in [16], [39], and [56].

A second major study in this area has been conducted by the Rand Corporation in the development of fly-away kits. The principal objective of this program was to maximize the military worth or essentiality of items to be stocked in a fly-away kit for a given operational period, subject to either a weight or cube constraint.[33] The military essentiality of the item was based on the relative importance and affect of a shortage of a particular part on the mission of the aircraft. A questionnaire approach was employed to obtain the information on military worth. The Rand questionnaire asked the affect of a part shortage on the mission of the aircraft. Psychometric scaling techniques were used to combine the judgment of several experienced maintenance men to categorize spare parts according to their essentiality. The numerical value of essentiality thus derived was combined with expected demand of an item by a multiplicative function and with weight to develop the quantities of the items to be contained in the kit. For a more detailed description of Rand's procedure in developing the fly-away kit see [37] and [53]. The same procedure developed here can be used in the construction of other supply tables for spare parts such as those prepared for vehicles.[34]

A third project is being conducted by Clark, Cooper, Field and Wohl, Incorporated, under the direction of the Bureau of Supplies and Accounts. It is entitled Military Essentiality Through Readiness Indices and will

[33] Ibid., p. 530.

[34] M.A. Geisler and H.W. Karr, "The Design of Military Supply Tables for Spare Parts", Operations Research, Vol. 4 (1956), pp. 431-442.

be discussed in a succeeding chapter. Basically METRI relates readiness to the fleet with its supporting items in simulated form to provide important decision-making information on problems of military essentiality and readiness. The ultimate objective is to get intelligence regarding the readiness of force units at any one time, how readiness might be improved, and the extent that individual components effect readiness. While not the ultimate, METRI is a significant step forward in the development of the military worth concept.

Nature of Repair Parts Demand.

Initial investigation by ALTP into the nature of repair parts demand was an attempt to find a meaningful operational variable to which usage rates could be related. It was found that the operational variables used (e.g., hours underway, engine miles steamed, etc.) could not be significantly related to usage.[35, 36] Indications are that the operational variables used were too gross. Additional studies showed that demand for individual items aboard ship was extremely low and sporadic, that there was practically no commonality of usage between individual

[35]H. Solomon, A Summary of the Logistics Research Project's Experience with Problems of Demand Prediction, Report Serial T-139, (Logistics Research Project, George Washington University, 1962), p. 5.

[36]Concerning the relationship of operation variables to usage, Geisler in [35] points out that demand for parts is not proportional to the activity level, but rather varies according to some probability distribution. These probability distributions have the general characteristic that the lower the average deman for the part, the greater is the relative variability of demand. Therefore, if the objective is to achieve maximum supply support from a given size inventory, it takes proportionately more units of a part to secure a given amount of protection against excessive demands at lower average demand rates than it does at higher demand rates. For a brief explanation of the more commonly used probability distributions see [50].

ships in terms of actual items used, that the same ship in different time periods experienced demands for different items, and finally that approximately 75 percent of the items in the population (i.e., installed and deemed wearable) were not demand at all over a four year period.[37] Based on these results, it seemed that the situation was one of uncertainty, as distinct from risk where some probability distribution may be assumed.[38] Given the observed high degree of uncertainty of demand, in particular the highly sporadic nature of demand, how to handle or control this condition for stocking policies was considered to be the most important problem.[39] Because of this observed nature of demand, it was concluded that the decision as to the range of items to be stocked should receive greater emphasis than the determination of the depth of each item to be stocked. First consideration should then be given to determining the range of items which are necessary for the operation of a mission.[40] This led directly to the study of military worth.

Development of Military Essentiality Codes

The approach used by ALTP to develop military worth measures was to ask questions on two levels, each representing a separate questionnaire.[41]

[37]W.H. Marlow, "Some Accomplishments of Logistics Research", Naval Research Logistics Quarterly, Vol. 7 (1960), p. 308.

[38]Solomon, "The Determination and Use of Military Worth...." op. cit., p. 530.

[39]Solomon, Report Serial T-139, op. cit., p. 6.

[40]Solomon, "The Determination and Use of Military Worth...." op. Cit.,

[41]For an excellent presentation on the development of questionnaires and their use in developing military worth measures for repair parts see [32].

One questionnaire, called the Maintenance-Potential Questionnaire, was directed at learning the effect of a part shortage on the component in which it is installed and was answered by technical personnel. The second questionnaire, called the Mission Effect Questionnaire, was used to determine the worth of the component to the mission of the ship and was answered by command personnel. The worth of a spare part, then, is a function of its importance to the parent component and, in turn, the importance of that component to the ship's mission.[42] The values were kept in the ordinal scale and stocking policies developed on these ordinal values or military essentiality codes[43] The objective was to maximize the endurance of a ship, i.e., the capability for sustained operation independent of logistical support other than by underway replenishment or other routine ways which do not interfere with the ship's ability to carry out an assigned mission.[44] Similarly the objective could be considered as maximizing the vessel's effectiveness for carrying out a mission while being completely independent of all external logistics support.

[42]Solomon, "The Determination.....", op. cit.

[43]Ibid., p. 531. Solomon makes an important observation in the evaluation of the inventory model and procedure using ordinal measure. He states that the evaluation is highly sensitive to the manner in which "worth" information is treated. For example, if arbitrary numerical values are employed, the evaluation of a model will be strongly dependent on these numerical values. With different numerical values, a particular inventory policy may appear better or worse than another. He continues by stating that an ordinal system of worth measurement presents difficulties in the process of model evaluation. For example, there remains the question as to how many low-worth shortages are equivalent to a moderately high-worth shortage.

[44]Marlow, op. cit., p. 308.

Results of the Military Essentiality Studies.[45]

Three significant results developed from the studies on military essentiality by ALTP. The first was a verification of the point that not all items are of equal importance or have the same military worth. For example, an evaluation of the Polaris submarine USS George Washington revealed the fact that only 15 per cent of the equipment and components were evaluated as having relatively high essentiality and only 11 per cent of the repair parts were in the same category.[46] Other studies indicate similar results, i.e., the over-all average of repair parts falling into the lower worth categories was 66 per cent.[47] A second result was that something specific can be done concerning military worth and that it need not remain as one of the intangibles in military inventory problems.

The third result was that the Chief of Naval Operations, recognizing the practical applications of this method, directed fleet wide implementation of the Military Essentiality Coding (MEC) program in November 1962. Shipboard decision-makers will utilize MEC to determine the priority of preventative maintenance schedules, to determine the priority of planned overhaul work requests, to evaluate casualty reporting, to evaluate repair

[45]For specific studies and results on the application of military essentiality coding to various combat units see the references indicated beside the units as follows: Ships [18] ; Polaris submarines [19] , [22] , [28], [44], [63] ; and aircraft [17] .

[46]W.T. Meyers, "Military Essentiality Coding", Newsletter (September 1963), p. 9.

[47]M. Denicoff, et al., "Summary of a Method For Determining the Military Worth of Spare Parts", Naval Research Logistics Quarterly, Vol. 7 (1960), p. 234.

parts readiness, to improve allowance lists, and to provide improved budget requests.[48]

Future Application

The techniques developed through the military worth studies, with gradual improvement of the method of measuring military worth, will find many future applications in the military decision-making process. Present techniques can be applied to system-stocking and echeloning of supply policies, to the provisioning or initial procurement of parts policies; and to determine the preference ranking of equipments for the schedules maintenance of Allowance Parts Lists on these equipments. These are but a few of the possible future applications. With the development of METRI, as we shall see in the succeeding chapter, even more significant possibilites are developed.

[48]Meyers, op. cit., p. 10.

CHAPTER VII

# MILITARY ESSENTIALITY THROUGH READINESS INDICIES (METRI)

## THE PROBLEM

One of the major problem areas in the Navy today is lack of an adequate readiness measure and a reporting and evaluation system of weapon system readiness.[1] This lack of an adequate readiness measure has caused decisions to be made on funding aspects which effect the support of weapons systems without an awareness of, understanding of, or a means of, determing the ultimate affects of such actions. Additionally, because there is no rigorous, objective method for indicating weapon systems readiness, decisions on determining ship or other weapon systems overhaul schedules or deterining when to strike a ship from the active list is less than optimal. Judgements of performance are made as to effects on immediate problems rather than against over-all Navy-wide standards of readiness requirements.

## READINESS

Naval readiness is the total product of Naval Logistics, thus depends on integration of matters of: personnel, material supply, availability, obsolescence, and deterioration as these are defined in their broad connotation.[2] At the core of Naval readiness is naval ship readiness. Ship readiness can be defined as that quality or state of a Naval

[1] Material Management Study Group, Material Management Study, Vol. I (Department of Navy, 1962), p. 191.

[2] J.E. Hamilton, Ship Material Readiness, Report Serial T-145 (Logistics Research Project, George Washington University, 1962), p. 138.

ship whereby it is prepared for use or action of any kind which might develop in war, or preparatory to, or training for war at any time.[3]

## OBSOLESCENCE AND DETERIORATION

Of the five factors affecting Naval readiness, two require additional explanation. Obsolescence is defined as the departure in design capabilities of a ship or other weapon system as it exists at any time from the best which could be on hand with full exploitation of the state of the art. Measurement of obsolescence is the means of telling what a ship is capable of doing if there is no deterioration. Deterioration is defined as the departure of the material in a ship or other weapon system from the brand new state or design capabilities and is a measure of reliability for future utilization.[4] Reliability is the probability of a system or equipment operating without failure for a required critical time. Measurement of deterioration is the means of telling how well a ship may be expected to perform within its designed limitations. Obsolescence is fought by local maintenance and by overhaul.[5]

Mills has further described the state of deterioration as follows:

> As material (repair parts, provisions, fuel, etc.) is consumed-(fails, wears out, is used, etc)- it is replaced. During the time it takes to replace the failed or used item, the ship is in a degraded state. The degree of degradation depends upon (1) the time to repair, a maintenance problem, and (2) the time to provide the replacement, a supply problem.[6]

[3] Ibid., p. 2.

[4] Ibid., p. 139.

[5] For an informative Study on obsolescence and deterioration and its relation to material readiness and its effect on military essentiality see [18] .

[6] H.F. Mills, "Military Essentiality", Newsletter, March 1963, p. 1.

It is the measure of this degradation of relative material readiness which we are seeking. Datum for the measurement will be the brand new condition of the ship.

## CURRENT METHOD OF MEASURING MATERIAL READINESS

The current measurement of the material readiness of ships, on which various decisions are made as to mission assignment and overhaul schedules, is based on two documental active sources of information. One is the INSURV report, which is a report of an inspection by the Board of Inspection and Survey at approximately two year intervals. The inspection determines the ship's physical deterioration. The second source document is the Casualty Report and is a report of material failures occuring aboard ship. It is submitted on an "as occuring" basis and serves as a guide to the ship's physical condition between INSURV inspections. Both of these reports serve only as rough approximations of ships readiness.

## A NEW APPROACH

The material readines-for-war of a ship is a function of its physical condition, its status as to provisions, stores, and ammunition, of the completeness of its allowance list of repair parts and of its personnel.[7] Ship readiness being a function of these variables then a measure or index of readiness could be developed, if a method representation or model could be devised to express the relationship or connection to the ship as a whole. This measure would reflect the readiness of the

[7]Logistics Research Project, George Washington University, <u>Survey of Command Logistics Problems</u> (Report Serial T-161, 1963), p. 20.

essential elements making up the whole. The index would incorporate the well-defined variables which affect the material readiness-for-war of the ship in some measurable amount. It would also incorporate the Military Essentiality of a unit of consideration in terms of the effect of its failure on a particular mission.[8] An approach to the development of such an index of material readiness which reflects the physical condition of the ship has been developed by Clark, Cooper, Field and Wohl, Incorporated, under the guidance of the Bureau of Supplies and Accounts.[9] The method is called Military Essentiality Through Readiness Indicies. It is a program for relating readiness of the fleet with its supporting items in simulated form to provide important decision-making information on problems of military essentiality and readiness. The ultimate objective is to get intelligence regarding the readiness of force units at any one time, how readiness might be improved, and the extent that individual components affect readiness.[10]

## METHOD

Clark, et al., briefly describe their method as follows:

> METRI involves the construction of an engineering model that functionally describes the operation of a force unit such as a ship. The model is nothing more than a vector chart, or series of charts, that shows how each item in a force unit contributes to its overall mission. When the model is completed, it is converted into a series of equations which are then put into a computer where they produce or simulate operation of the force unit. In this way, the effect of each individual item in the force unit can be traced in a system-wide

[8] Ibid.

[9] Clark, Cooper, Field and Wohl Incorporated, METRI Interim Working Document (18 July 1963).

[10] Ibid., p. i.

fashion. How a unit affects other units and the force unit as a whole can be determined. Various combinations of item performance or failure of one or more to perform can be traced as tested. The simulated model of the force unit will reproduce in a short period of time experience that would take many years of conventional operation.[11]

## A STEP FORWARD

The METRI concept is an out-growth of earlier work on material essentiality done by the Logistics Research Project, George Washington University, and represents an additional step forward. The development of the concept was done principally aboard the USS Brownson. A more specific explanation of the METRI as it applied to ship follows.

## THE HIERARCHY STRUCTURE

A ship can have one mission or more than one mission, some or all of which may be of a continuing nature.[12] The readiness of the ship to perform its mission can be related to the various sub-systems acting as a total system. The sub-systems can in turn be broken down into equipment and so forth, decending the ship's hierarch, a level at a time, until the individual bits and pieces are reached. In this manner parts performance can be related to mission performance through a structured set of hierarchical functional relationships.[13] Since each item in the hierarchy, starting at the top, depends upon the performance of items at the next lower level, the entire ship structure can be reproduced in both chart form and mathematically. Readiness to perform a mission can,

[11] *Ibid.*, p. 2.

[12] For development of the weighting factors of the missions for a multi-mission ship see [51].

[13] Mills, *op. cit.*, p. 2.

therefore, be expressed by a mathematical relationship that links items of support to mission through the intervening ship structure.[14]

## THE MODEL

At the heart of the METRI concept is a sophisticated type of engineering model. The model realistically shows how all items in a system are inter-related and how each affects the total system. The model is developed from a charting system in symbolic form which portrays accurately the functional relationships of all the parts that go to make the total system. The building blocks of this charting system are three kinds of structures, embracing six classes of relationships. The three types of structures are Delta, "V", and "X", while the classes of relationships are supplements, complements, alternatives, sequences, coordinates, and collaterals. Additionally, there are some underlying axioms or assumptions.[15] This functional model of the ship developed through charting is then expressed in mathematical form. The formulas are then computerized to provide a wide range of information regarding readiness and material essentiality. With the computorized model, simulated readiness under varying operating conditions can be done making it possible to predict events and conditions, so that corrective courses of action can be planned. The measurement of material essentiality is accomplished by varying the state of readiness of the inputs and determining affect on the total readiness of the ship; therefore in this case essentiality of an item is the degree to which it affects overall

[14]Clark, etal., <u>op</u>. <u>cit</u>., p. 3.

[15]For further explanations of the structures, relationships, and axioms see [13].

readiness. Conversely, readiness is the sum total of essential services provided by components and other input items. Thus, the model clearly shows that essentiality can not be considered without considering readiness, and conversely, readiness can not be considered without taking into account essential contributions of subordinate items.[16] Readiness measures then become an expression of a percentage of designed capability for a specific operating condition and in relation to a specified mission.

## ABSOLUTE VS. RELATIVE READINESS

METRI can measure the affects of four of the factors contributing to readiness, but it can not measure obsolescence. Additionally, METRI only measures relative readiness, and absolute readiness. Clark, et al. make the following statement concerning this important aspect of readiness:

> Readiness has two critical aspects, namely, absolute readiness and relative readiness. Absolute readiness deals with strategy and combat command. It pertains to overall strength and how that strength compares with possible combinations of enemy strength. Relative readiness deals with the strength of a given force system. It is the percentage of full design or other designated capability that a force has at a specific time. It is largely a matter pertaining to such factors as the condition of equipment, staffing of force units, and adequacy of funds.[17]

## FURTHER APPLICATIONS

This concept cr technique for relating readiness of a ship with its supporting sub-systems to determine vital information both on readiness of the ship and on essentiality of supply items can be further

[16] Clark, etal., op. cit., p. 69.

[17] Ibid., p. 70.

implemented up in the heirarchy to include entire force units. Even at its present stage of development METRI can provide a wealth of information to assist in planning and budgeting and in command and logistical decisions. With further development it will enable naval commanders to determine how ready a force unit is to meet a given mission; point out the best way to bring a force unit up to a given state of readiness, and will show in rank order the essentiality of supply items needed to do this. The budgereers will be furnished with information relating readiness to various levels of funding. Maintenance personnel will receive intelligence regarding the trade-off of reliability and inventory back-up. Ship designers will gain valuable insights into the functional operations of force units and how they relate to one another in carrying out a mission.[18, 19]

Because of its sophistication and complexity, further extension of METRI above the ship level will be costly. Also, keeping charts current will present a tremendous problem. METRI is being extended to all destroyers of Destroyer Squadron 32. Also, METRI is being dovetailed with the Standard Navy Maintenance Management System (SNMMS) to the greatest extent possible; however, METRI is primarily an information system to provide data regarding material essentiality and its affect on readiness while SNMMS is a program to raise the level of ship's readiness through maintenance actions.

## CURRENT STATUS OF METRI

The METRI project has now been designated Project Number NT-F-015-01 under the cognizance of the Bureau of Supplies and Accounts. It

[18]Clark, et al., op. cit., p. 1.

[19]For additional applications of METRI see [13], pp. 93-95.

is divided into nine sub-projects entitled as follows: Complete USS Ellison Model, Investigate Application of METRI Model to Inventory Systems, Investigate Application of METRI Model to Operational Readiness Systems, Investigate Application of METRI Model to Maintenance Systems, Investigate Application of METRI Model to Personnel Systems, Investigate Application of METRI Model to Budgeting Systems, Investigate Application of METRI Model to Design Systems, Evaluate Extension of METRI Model to All Forces Afloat, and Evaluate Integrated Systems. The first eight subprojects are concerned with the actual modeling of ships. The first subproject is concerned with the actual modeling of a prototype ship. The eighth listed subproject examines the feasibility and cost of modeling all ships. The second through the seventh are concerned with the various applications of the ship models. In these, each application is investigated independently as though the models were to be applied to it alone. The last subproject listed will examine systems which consider all applications simultaneously. In addition to these applications it is believed that the basic METRI concept can be applied to some Joint Chief of Staff and Department of Defense type problems such as readiness reporting, and in such a way as to provide a conceptually uniform system throughout the Military Establishment.

Several phases of each of the subprojects have been completed and the prospects for further applications are very promising. The ultimate object of the project will be the specification of methods and systems which will improve decisions in many areas, including operations, maintenance, personnel, supply, design and budgeting.

## CHAPTER VIII

## SUMMARY AND CONCLUSIONS

The military decision-maker of today is faced with many complex decisions and problems requiring specific solutions. The military complexities of the problem have superimposed upon them economic, political, moral, social, and technological complexities. The sheer size of the problems and the extreme national importance of making correct military decisions can not be overemphasized, as they may affect our safety and very survival as individuals and as a nation. Static considerations are complex enough, but when time and the uncertainty of future events are introduced as another element of the problem it becomes even more complex. In many cases this uncertainty is not a simple case of risk and an associated probability, but consists of true uncertainties of outcomes of various decisions and of actions and reactions of the enemy.

The general nature of the problem facing the military decision-maker is that he has certain fixed resources which, according to the state of technological development, may be combined to give certain alternatives by which he can reach his stated objective or mission. These alternatives may either be infeasible, feasible, efficient or optimal. If he wishes to accomplish the objective by the minimum use of resources then he would wish to choose the optimal alternative or optimal combination of alternatives.

The consideration of all the variables and possible alternatives and the weighing of their significance on the problem at hand in order to arrive at an optimal decision is beyond the ability of the human

mind. These problems must be reduced to manageable proportions and feasible courses of action found, which may only be sub-optimal and subject to effects of spillovers and their attendant error possibilities. Although in the past many of the decisions were made solely on intuitive judgment, the development of modern tools and techniques of managerial analysis and decision-making enable these intuitive judgments to be altered or strengthened by a more structured approach. Intuition and judgement are being supplemented with systematization and substantiation through investigations of measurable quantities that can either support, extend or contradict the intuitive judgement. These structured approaches to military decisions and problems consist mainly of the scientific method and economic analysis.

There cannot be any valid presumption regarding the universal and uniform applicability of the scientific method and economic analysis in the field of military decision-making; however, these techniques provide useful and valuable means of structuring the decision making process until some more suitable method is developed. Structuring the decision process and quantifying those variables that can be quantified with reasonable accuracy, will provide additional insight into the problems of the military decision-maker and provide models of the system which will be more descriptive and predictive, and will lead to more rational and consistant decisions. In making rational decisions, the aspect of military worth, cost, quality and time must be weighted and integrated into the analysis of alternatives.

Because there is no unique correct solution to military decision problems, given the present state of the art, the structured methods are only an aid in this process and not a substitute for common sense

and sound experienced judgment. The military decision-maker must not loose sight of the importance of the factors or variables that remain unmeasured and the assumptions that lie behind the quantification of the measured variables. He must continue to examine ways of improving his choice of payoffs and his criteria of judging the relative merits of alternatives. He must keep abreast of the advancements in the sciences of economics, mathematics, statistics, and electronic data processing which have resulted in the development of theories and techniques that have special application in the solution of complex problems peculiar to modern military management in all of its ramifications.

At the heart of the structured method is the selection and measurement of suitable criteria. Criteria are tests by which one alternative output or system is chosen over another. Criteria may also be defined as the practical counterparts or approximate indicators of, or substitutes for, the function which the decision-maker would like to maximize in choosing among alternative courses of action. In developing criteria the decision-maker is trying to develop scales of effectiveness.

Criteria may take many forms. A criterion may be factual or value or a combination of both. The aim is the answering of the right question and the selection of an optimal solution. In many cases application of a criterion may result in selection of an efficient system, relying on the intuitive judgements of a well-informed decision-maker to select one of the efficient systems in the neighorhood of the optimum.

Selection of an appropriate criterion is a difficult task. In the

business world, the business entrepreneur has selected the objective of maximizing profit. The criterion used to measure the accomplishment of this objective is dollars. The market system and its associated pricing structure provides a great deal of free information expressed in the common denominator of dollars. The military decision-maker has as his objective victory in war, but he has no comparable mechanism at his disposal with a convenient common denominator of dollars to measure alternative methods in obtaining this objective. It is difficult to express value of different weapons systems for completing some mission. Many weapons systems have not yet been tried. In any event, decisions must be made on the basis of some idea of the relative importance of the various objectives. The appropriate criterion would be military worth or military value. In years past little effort was made to quantify military worth, but developments in utility theory and probability theory, improvement of measurement techniques, and development in mathematical formulations have given added emphasis to the possible quantification of subjective data. Much of this work is still in the initial stages of being transformed into a practical tool for military decision-making.

If we are going to measure military worth, values or utilities, a scale must be devised to represent these values so that various comparisons and mathematical manipulations can be made with these values. Measurement scales may be selected by comparing the analytical demand to be made upon them. Two important analytical features of a scale are its operational character and its descriptive power or information provided by the scale values. Three basic types of scales starting with the one possessing the least analytical potential are nominal, ordinal

and cardinal, which may further be subdivided into interval and ratio scales. The use of one scale rather than another is determined by the problem to be approached and the analytical potential required, and not by the method used as a basis for constructing the scale.

Military worth may be conceived as a subdivision of the more general field of worth and value. Presently there is no universally applicable definition of military worth. It greatly depends on the level of command at which it is being used, the context of the problem, or the criteria used to measure it. At the national level it may be defined in terms of contribution to winning or deterring some kind of war. At the level of the individual military decision-maker, it may be described as his preference for, or amount of satisfaction he receives from, having a certain military entity (the concept of utility theory). While the terms military worth and military value are used in many cases interchangeably, they are two separate concepts.

The concept of military value may be related to the phenomenon of choice. Military value may be defined as that which determines choice. By defining military value in this manner, a quality of the individual rather than an inherent quality in an object or entity is being sought. The aspect of the military value dimension which describes the individuals disposition towards an object may be called preference. An important fact to focus upon is that preference determines choice and not the size of the number chosen to represent preference. Habit, custom, military experience, training, tastes and preference may all be considered important influences on the choice of a military decision-maker. Analytically it is at present convenient to aggregate all factors contributing to the choice decision of an individual decision-maker into

the single concept of military value.

The concept of military worth may be related to that quality or sum of qualities of an entity rendering it essential, valuable, or useful. Military worth then may be understood to mean physical utility of various alternatives. Military value is related to military worth in that value is the estimated or assessed worth, usefulness, or essentiality an individual places upon an entity. Military value judgements may be arbitrary, and in a sense conventions of the time and place, but are mainly based on the military worth and imputed importance of an alternative.

The ideas of military worth and military value have proven difficult to formalize because they are not absolute, because they have not yielded to a single scale of measure, because of countless possibilities of exchange or trade-off in measures of value which vary with circumstances, and because it has not been possible in most cases to dissociate moral ana social value from material values. The development of a suitable procedure to measure military worth or value would be a significant step forward in the evaluation of alternatives and in improved decision-making. In approaching this problem of formalization and measurement of military value or worth two basic questions must be answered. Who (in the case of value) or what (in the case of worth) should be measured? How should value and worth be measured and in relation to what?

The answer to the question of who is to be measured in the measurement of military value depends on the problem being considered. How to measure military value or preference may be approached by two aspects, introspection and behaviorism. The introspection method uses verbal responses of individuals involved to certain questions to develop

military value scales. Behaviorism measures military value by certain actions of the individual, such as presenting an individual with an array of objects or entities to choose from.

A third methodology, formalized by VonNeumann and Morgenstern, called Gaming Theory, may be used to develop weak interval scales of military value. To understand this method, it must be realized that there are three choice contexts as follows: (1) <u>certainty</u> where the outcome of a choice is known, (2) <u>risk</u>, where a given choice implies several possible outcomes, each associated with a known probability distribution, and (3) <u>uncertainty</u>, where the form of the probability distribution is unknown. The Game Theory methodology develops military value scales which are generalized such that they would indicate the choice of an individual under conditions of risk. The basic assumption behind the generalization is that for each person there exist numerical constraints, called utilities, associated with the various possible outcomes of his actions, given the external events not under his control. The Game Theory scales make no statement concerning the individuals feelings toward an object. Rather, they assume certain rational consistencies in his behavior, namely that he seeks to maximize his expected utility or military value and the ability to represent behavior through the use of choice scales.

There are various approaches and methods that are used in measuring military worth depending on the problem and the amount of information and operational characteristics the measure must provide. Here again we must answer the question: What to measure and how to measure the selected criterion or criteria? In this economic approach two elements, cost and effectiveness (or quality), are considered when

evaluating an alternative. Effectiveness may be physical utility or combination of physical utilities, such as expected kill, target destruction, etc. If multiple criteria are used to evaluate effectiveness, then generally some weighted factor will have to be assigned to each, to derive over-all effectiveness. The goal is to optimize the physical utility within the constraints of the problem or system. We say we are trying to optimize military effectiveness, but this is obviously a subjective idea rather than an objective, physical, measured utility. This method substitutes some set of physical measurable utilities which it is hoped represents a true element of effectiveness. The measure should reflect some fundamental attribute, the more basic the better, since otherwise an essential index could hardly be expected to result.

Using the structured method and the measurement techniques discussed above, military value and military worth may be quantified. By thus making these subjective concepts objective, they can be predictive, descriptive or optimized. At least trends can be seen and measured to determine if we are moving in the right direction. These numerical measures can be manipulated by mathematical use of systematic methods for calculating the effects of several variables, brining explictly to light assumptions underlying the analysis, and providing insights into the problem. Insights give clearer perception of the trade-offs made in weapons decisions, and explicit recognition of these trade-offs in actual program decisions may provide substantial benefits in terms of improving the allocation of national defense resources.

It must be kept in mind, however, that military worth or value evaluation and measurement is highly sensitive to the manner in which

worth or value information is treated. If arbitrary numerical values are employed, the evaluation of a model used to develop and test alternatives will be strongly dependent on these numerical values. With different numerical values, a particular alternative may appear better or worse than another. For example, if an ordinal measurement system is used it would be difficult to determine how many low-worth entities are equivalent to a high-worth entity. This is the problem of aggregation of micro-military values to obtain macro-military values with the many complicated interfaces and interrelationships in and among various alternatives. For these reasons, and in order to assess the usefulness of military worth or value scales, the decision-maker must be aware of the significance of the numerical measures being used to represent military worth or value and the assumptions that were made in the development of the scales giving rise to these numerical measures. Generally, no absolute value of military worth prevails or is discernible at this time, only a relative value developed as entities are brought into comparison with one another, which means that only trends are measurable at this time.

Interest in the military worth and value concept has been sharpened through the emergence of appropriate analytical tools in dealing with military worth, through the identification of problems which submit, with realism, to formal mathematical treatment, and through the growing awareness of its importance. Some general military decision problems which may effectively use military worth measures in their solution are the evaluation and selection of weapons systems, military operations, and executive control systems. Generally, all that is required in these problems is to rank the various alternatives by military

value or military worth. The military worth or value of these alternatives could be evaluated by the methods previously discussed: however an additional aspect in measuring military worth and value is seen in a method suggested by Peck and Scherer.[1]

Peck has proposed the construction of a military worth function based on a comparison of the quality of one nation's weapon systems relative to the quality of its rival's systems. This is based on the concept that the military value of a weapon system depends upon the quality of counterpart weapons possessed by the enemy, and brings into play the factor of obsolescence. Obsolescence is defined as the departure in design capabilities of a weapon system as it exists at any time from the best which could be on hand with full exploitation of the state of the art. To accomplish the ranking of weapons it is necessary to formulate a military worth function reflecting this relativity notion in conjunction with corresponding possibility curves of time, cost and quality associated with each weapon system. Peck accomplishes this through a parity function from which military worth may be measured. In this case military worth is broadly defined in terms of the contribution a weapon system makes to the maintenance of peace or the prosecution of warfare. Weapons systems can now be ranked on a priority ladder according to their net military worth as obtained from the parity function.

In addition to these general applications, military worth measures may be effectively used in military logistics problems such as in the

[1] J.M. Peck and F.M. Scherer, The Weapons Acquisition Process: An Economic Analysis (Boston: Harvard University Press, 1962).

development of priorities, in the improvement of equipment allocation, and in inventory control. The application of the military worth concept has proved very fruitful and is at present findings its greatest application in the area of inventory control. Generally, military worth or value in this area is called military essentiality and is broadly defined as the importance a repair part, equipment, ships, etc, has in relation to the accomplishment of a stated mission or missions or in relation to the readiness of a unit to accomplish its missions.

A significant feature of the inventory problem in the military establishment is its very close connection with the problem of military worth or strategic value. Inventories are held in order to support some current strategic plan and to permit the feasibility of future and uncertain strategic plans; therefore not all items are of equal importance or have the same military worth. The importance of the objective or mission will determine their importance. From this it is apparent that military worth plays an important role in logistic planning and requirements determination.

The complexity of the military inventory problem is without parallel in civilian industry. Before any importance military decisions on inventory levels can be made, certain basic assumptions must be made about the probability of war and the time and duration of the war. Next, the objectives must be stated. The objective of the Naval Supply System is to improve the capability of the Navy to destroy enemy targets in war. In this effort, the readiness of weapons systems depends on reliability and maintainability of the equipment comprising the system. Maintainability is in turn a function of both supply and maintenance. The lack of immediate or extremely rapid accessibility of

some items of military equipment or repair parts could in some cases be as serious as its nonexistence and could cause consequences of an extremely grave nature. This cost of depletion must be carefully analyzed. For this reason, the higher the military essentiality of an item the closer to the end-user should be the inventory support. Thus one factor to be considered in the echeloning of supplies certainly should be military essentiality of the items. The capability of the Navy could be improved by proper echeloning of the material inventory. This is true because the closer an item is to the end-user, the less elapsed time there is in filling the user's order, consequently there is an increase in readiness.

The introduction of even a crude military essentiality system into the supply system should certainly lead to the establishment of inventory levels more in accordance with the strategic importance of various items. Goods might be divided into categories where depletion was of vital importance, of moderate importance, and of little importance. Probability figures could then be assigned to each of these major categories, expressing to some extent these varying degrees of importance. Failure to do even this rough approximation of the importance of inventory items is to implicitly postulate that all items in an inventory system are of equal worth or essentiality under all situations.

The basic approach in developing the military essentiality of repair parts has been through the use of a questionnaire and psychometric scaling techniques to quantify the answers to the questionnaire. The questionnaires are directed at two levels, at the command level to determine the effect of an equipment loss on the mission of the unit, and at the maintenance level to determine the effect of a part failure on

the operation of the equipment. This approach to stocking repair parts based on military essentiality was brought about because the demand for individual repair parts was extremely low and sporadic, because there was practically no commonality of usage between individual units in terms of actual items used, and because no direct relationship between operational variables, such as steaming hours or flying hours, and demand rate could be determined.

The use of the military essentiality techniques has proven highly successful, particularly in developing allowance lists for Polaris submarines. In addition, military essentiality aboard ship can be used to determine the priority of preventative maintenance schedules, to determine the priority of planned overhaul work requests, to evaluate casualty reporting, to evaluate repair parts readiness, to improve allowance lists and to provide improved budget requests. It demonstrates that something specific can be done concerning military worth and that it need not remain as one of the intangibles in military problems, particularly in inventory control.

A logical extension of military essentiality coding is the development of the project METRI (Military Essentiality Through Readiness Indicies). Basically, METRI relates readiness of the fleet with its supporting items by an engineering model in simulated form to provide important decision-making information on problems of military essentiality and readiness. The ultimate objective is to get intelligence regarding the readiness of force units at any one time, how readiness might be improved, and the extent to which individual components affect readiness. METRI will enable naval commanders to determine how ready a force unit is to meet a given mission, point out the best way to bring

a force unit up to a given state of readiness, and will show in rank order the essentiality of supply items needed to do this. The budgeteers will be furnished with information relating readiness to various levels of funding. Maintenance personnel will receive intelligence regarding the trade-off of reliability and inventory back-up. Ship designers will gain valuable insights into the functional operations of force units and how they relate to one another in carrying out a mission. METRI may also find application to some Department of Defense type problems such as readiness reporting, and in such a way as to provide a conceptually uniform system through-out the military establishment.

METRI has three disadvantages. Because of its sophistication and complexity, extension of the method above the unit level will be expensive. The task of keeping the engineering model current will be a tremendous problem. Finally, METRI does not provide information on obsolescence. There exists a need to measure the relationship of one weapon system in relationship to other weapons systems and in relation to the enemy's weapons systems. METRI does not provide this and the use of monetary criteria is too limited, since it leaves out of account the military worth of alternative defense schemes. Calculating military value on a parity basis over time leads to the important conclusion that the United States must be prepared for the worst at all times by having a diversified inventory of weapons as technically advanced as possible.

There still remains the continuing task of clarification of the military worth concept as well as the derivation and application of military-worth measurement. It was the intent of this review to bring together in one source some of the current developments in the concept

of military worth and to show the many and varied applications that can be made of military worth measures. While the military worth problem is complex, this is at least matched by the importance of doing something specific about the problem.

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APPENDIXES

APPENDIX A

OUTLINE OF A STRUCTURED METHOD OF DECISION MAKING

The following outline is a structured method of dealing with decision problems. The detail and extent to which a decision maker will want to go into each step of the procedure will depend on the problem being considered, on the time available for its consideration and solution, and on the staff personnel available to the decision-maker. The recommended procedure is:

A. To clearly and logically state objectives with a description of the assumptions on which they are based,

B. To become aware of the problem,

C. To make a precise statement of the problem and the assumptions made,

D. To establish a solution criterion or a measurement of success,

E. To collect pertinent data relevant to the problem by

1. Experimental Methods,
2. Observational Methods, and/or
3. Statistical Methods,

F. To sort and analyze the data so as to produce a hypothesis, which is called a model. The model may be of the following types:

1. Physical Model,
2. Quantitative Model,
3. Qualitative Model.

The usefulness of the model is determined by its benefit and not necessarily by its exact representation of the real world.

G. To formulate a solution to the hypothesis by testing the model in predicting results in various circumstances and with various parameters,

H. To survey alternative solutions,

I. To establish controls or parameters of the solution,

J. To test the hypothesis with current data. The test of the hypothesis may be conducted at three levels:

1. Common Sense Level-Trial and Error
2. Empirical Level-Statistical Data
3. Scientific Level-Experimentation and observation.

K. To implement the hypothesis by putting the solution to work,

L. To establish controls and feedbacks for the implemented solution or alternative.

APPENDIX B

MODERN TOOLS OR TECHNIQUES USED IN DEALING WITH COMPLEX PROBLEMS [1]

A. TOOLS FOR COPING WITH COMPLEXITY

1. Mathematical Programming. These are basically static considerations. Linear programming is a member of this family.

2. Dynamic Programming. The time element is introduced.

3. Symbolic Logic. This is a method of putting decisions into symbols to determine logical consistancy in an endeavor to make decisions more rational.

4. Factor Analysis. This is a method of determining key elements of a complicated problem by factoring or breaking it down into its essential parts.

B. TOOLS FOR COPING WITH VARIABILITY

1. Probability Theory. This theory makes use of various density functions.

2. Queuing Theory (Waiting Line Problems). Use of this theory can be broken down into four practical problem solving areas:

a. Facilities Problems,

b. Scheduling Problems,

c. Sequencing Problems,

d. Line Balancing Problems.

C. TOOLS FOR COPING WITH LACK OF INFORMATION

1. Sampling.

2. Statistical Inferences. The problem here is in determining whether there is lack of information, rather than variability. There

[1]James P. Cowie, "Modern Tools or Techniques Used in Dealing with Complex Problems, "(lecture delivered at the U.S. Naval Postgraduate School, Monterey, California, April 17, 1964).

are three sub-areas:

a. Test of Significance,

b. Design of Experiments,

c. Analysis of Variance.

3. <u>Monte Carlo Analysis</u>. This method uses random events and simulation by use of random number tables or some other random number generator in studying various problems.

4. <u>Simulation</u>. Simulation may be in the form of numbers or mathematical formulas. Electronic Data Processing has greatly added to the usefulness of this tool.

D. MISCELLANEOUS TOOLS.

1. <u>Replacement Processes</u>. A process of evaluating decisions to replace capital equipment based on cost, probabilities, life of equipment, and estimates of action by competition.

2. <u>Scientific Inventory Analysis</u>.

3. <u>Network Analysis</u>. This is a useful tool in production-management, program-management, or in considering routine problems. The most prominent example of this technique is PERT.

4. <u>Information Theory</u>.

5. <u>Econometrics</u>. This is a combination of mathematics and economics, using utility theory, marginal analysis, and other economic analysis techniques. It is a quantitative approach to economics.

6. <u>Differential Calculus and Matrix Algebra</u>.

APPENDIX C

THREE FACTOR METHOD OF LOGISTIC PLANNING

| Factor | Basic Measurement |
|---|---|
| 1. Military Activity (Independent Potential, e.g., days without support) | 1. Some unit of activity such as flight hours or steaming hours. |
| 2. Commodity Consumption (Conversion Factor) | 2. Units of material consumed per unit of activity. |
| 3. Judgement Factor (To reflect expected deviations from the standard conditions) | 3. Estimation of Military Activity. Measures degree or extent of military activity necessary for some planned operation. |

Expected Requirements = (Independent Potential) x (Conversion Factor) x (Judgement Factor)

APPENDIX D

FOUR FACTOR METHOD OF LOGISTIC PLANNING

| Factor | Basic Measurement |
| --- | --- |
| 1. Protection Level (PL) | 1. Probability of the loss of a specified unit of the task force or ship. |
| 2. Military Essentiality (ME) | 2. Measurement of relative importance of each kind of material has on mission limitation due to non-availability of the item. |
| 3. Usage Estimates (UE) | 3. Expected number of expenditures for each kind of material per unit per unit-mission time period. |
| 4. Opportunities For Usage (OU) | 4. Number of units in task force for which material required and possible rates of usage. |

Expected Requirements = PL X ME X UE X OU